A Thesis on

“STUDIES ON BATCH DRYING CHARACTERISTICS AND TRANSFER COEFFICIENTS OF THE FOOD GRAINS AND VEGETABLES IN A FLUIDIZED BED DRYER USING ANN METHOD”

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER IN TECHNOLOGY (RESEARCH)

IN

CHEMICAL ENGINEERING

BY

MS. SUBASINI JENA

(Roll No. 609CH301)

Under Esteemed guidance of

Dr. Abanti Sahoo

DEPARTMENT OF CHEMICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

AUGUST-2011

ACKNOWLEDGEMENT

I express my sincere gratitude to my guide Prof. Abanti Sahoo, Chemical Engg. Dept., National Institute of Technology, Rourkela, for her valuable guidance, support, constructive criticism, and encouragement during every stage in the completion of my project report.

I express my deep sense of gratitude to Prof. S. Mishra, Prof. S. Khanam, my teachers of Chemical Engg. Dept., National Institute of Technology, Rourkela, for their inspiration and encouragement throughout the course of M.Tech. (Res.) studentship.

I would also like to thank HOD, Prof. R. K. Singh for his kind help to make this report complete.

Last but not least I thank all my friends and staff of Chemical Engg. Dept. who assisted me directly and indirectly in completion of this thesis work.

(Ms. Subasini Jena)

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

ROURKELA-769008(ORISSA)

CERTIFICATE

This is to certify that the work in this thesis report **"Studies on Batch Drying Characteristics and Transfer Coefficients of the Food Grains and Vegetables in A Fluidized Bed Dryer Using ANN Method"** by **Ms. Subasini Jena**, has been carried out under my guidance in partial fulfillment of the requirement for the degree of **Master** of Technology (Res.) in Chemical Engineering, session 2009-2011 in the department of Chemical Engineering, National Institute of Technology Rourkela and this work has not been submitted elsewhere for a degree.

Dr. (Mrs.) A. Sahoo
Associate Professor
Department of Chemical Engineering
National Institute of Technology
Rourkela

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Attempts have been made to study the drying characteristics for different grains and vegetables by carrying out experiments in a fluidized bed dryer. Drying characteristics have been analysed in terms of moisture content and diffusivity for grains and vegetables dried through the laboratory scale fluidized bed dryer. Characteristic drying curves have been plotted. The effects of different system parameters (viz. temperature, time, and density of material and fluid velocity) on the drying performance i.e. on moisture content and diffusivity of the sample have been studied in the present work. Temperature dependence of mass transfer coefficients have been established in terms of Arrhenius type of relation.

Drying curves of different samples indicate that drying occurs mostly in falling rate period due to internal diffusion as effective diffusivity of different samples were found to decrease with increase in drying time. Fick's second law of diffusion is found to be applicable for the drying process during the falling rate period. Attempt has also been made to develop correlations for the moisture content and diffusivity of the samples relating the respective experimentally observed data with the different system parameters on the basis of dimensional analysis which have been validated by Artificial Neural Network analysis. Finally the calculated values of the moisture content obtained through the Dimensional analysis and Artificial Neural Network analysis have been compared with the experimentally measured values. Standard deviations and mean deviations for different samples were found to be less by both Dimensional analysis and ANN-analysis respectively. Very good agreement between the calculated values by ANN-analysis and experimental data proves that the Neural Network training is proper and it has learned well the behavior of the different parameters.

CHAPTER-I

Introduction

Drying is an important downstream operation in chemical industries because of several reasons. Some among them are customer acceptability, process requirement to increase shelf life, to reduce oxidation, to minimize biological damage and to reduce perishable nature of the product. In many practical applications, drying is a process that requires high energy input because of the latent heat of water evaporation and relatively low energy efficiency of industrial dryers. Thus expensive energy is depleted only to produce low grade heat for drying.

Fluidized bed dryers provide more efficient air-solid contact and hence, faster drying than any other methods because homogeneous mixing and uniformity can be achieved by fluidization (Davidson et al. 1985). The process of fluidization with hot air is highly effective for the drying of powders and wet granular materials. The use of fluid bed drying for granular materials is now well established and literally thousands of fluid bed dryers are operating throughout the food and chemical processing industries in the drying of coarse materials, grains, fertilizers, chemicals, and minerals, pharmaceuticals and food products among other solids. Fluidized bed dryers are also currently used commercially for drying various materials.

Several techniques of drying have been developed in the past. They may be classified in thermal drying, dielectric drying, and vacuum drying. Among them thermal drying is an easy and well adopted operation. Depending on type of heating, flow of heating medium, flow of drying material and geometry of dryer, several types of dryer can be used. Among them solar drying is the simplest and well adopted from the time immemorial where radiation from sun is used as heating source, but it takes long time and large floor space.

Drying of solids is an important process in many chemical, food, and transformation industries because of the many advantages i.e. the reduction of moisture in solids presents the following advantages:

(a) Improves the solid handling.

(b) Improves the use of the solid as raw material.

(c) Reduces the loading and transport costs.

(d) Increases the storage capacity.

(e) Reduces fermentation processes inside the solid during storage and transport.

Fluid bed processing involves drying, cooling, agglomeration, granulation, and coating of particulate materials. It is ideal for a wide range of both heat sensitive and non-heat sensitive products. Uniform processing conditions are achieved by passing a gas (usually air) through a product layer under controlled velocity conditions to create a fluidized state. In fluid bed drying, heat is supplied by the fluidization gas, but the gas flow need not be the only source. Heat may be effectively introduced by heating surfaces immersed in the fluidized layer.

Advantages:

- In fluidized beds, the contact of the solid particles with the fluidizing medium (a gas or a liquid) is greatly enhanced when compared to packed beds. This behavior in fluidized combustion beds enables good thermal transport inside the system.
- Good heat transfer between the bed and its container which can have a significant heat-capacity whilst maintaining a homogeneous temperature field.

- High heat and mass transfer rates, because of good contact between the particles and the drying gas.
- Uniform temperature and bulk moisture content of particles, because of intensive particle mixing in the bed.
- Excellent temperature control and operation up to the highest temperature.
- High drying capacity due to high ratio of mass of air to mass of product.

Fluid bed drying offers advantages over other methods of drying of particulate materials. Particle fluidization gives easy material transport, high rates of heat exchange at high thermal efficiency while preventing overheating of individual particles.

An artificial neural network is an information–processing system that has been certain performance characteristics in common with biological neural networks. Artificial neural networks have been developed as generalizations of mathematical models of human cognition or neural.

An artificial neural network is developed with a systematic step-by-step procedure which optimizes a criterion commonly known as the learning rule. The input/output training data is fundamental for these networks as it conveys the information which is necessary to discover the optimal operating point. In addition, neural network make non linear natures processing elements a very flexible system.

Objective of the work:

(i) To study the drying characteristics (mainly the diffusivity, mass transfer coefficient, activation energy and the drying rate) of different samples using a fluidized bed dryer.

(ii) To develop correlations/expressions for diffusivity and moisture content on the basis of regression analysis.

(iii) To validate the developed correlations by using ANN analysis.

CHAPTER-II

Literature Survey

2.1 Introduction

Drying is essentially a process of simultaneous heat and mass transfer. Heat necessary for evaporation is supplied to the particles of the material and moisture vapor is removed from the material into the drying medium. Heat is transported by convection from the surroundings to the particle surfaces and from there by conduction, further into the particle. Moisture is transported in the opposite direction as a liquid or vapor on the surface; it evaporates and passes on by convection to the surroundings.

Dryers can be classified as batch or continuous types depending on the mode of operation. In general batch dryers are preferred for small scale operation. Fluidized bed drying produces full agitation of solid particles by hot air where heat transfer is extremely high and uniform. The product is dried fast without appreciable loss of heat. Fluidized bed dryers also provide high drying capacity and lower initial cost.

Drying characteristics of grains are complex. The moisture associated with seeds is of many forms viz. a) Chemically bonded b) physicochemically bonded and c) mechanically bound form, depending on the bond strength of moisture. The nature of drying depends on the formation of its bond with the seed. For instance macro-capillary water enters in by liquid flow; on the other hand swelling moisture is removed or dried by diffusion through the cell wall. Hence the removal of moisture from seed becomes difficult.

Recent developments of the regime of fluidization and subsequent design modifications have made fluidized bed drying a desirable choice among other dryers. However, like other types of conventional convective drying process, fluidized bed drying is a very energy intensive process in industry. The efficiency of a conventional drying system is usually low depending on the inlet air temperature and other conditions. It is therefore, desirable to improve the efficiency of the drying process to reduce the overall consumption of energy.

2.2 The different terms used for drying experiments are as follows:

2.2.1 Moisture Content (M_C)

Percent Moisture on weight basis is the moisture associated with feed material expressed as the percentage of weight of feed material.

Weight % moisture content on weight basis $= \frac{\text{kg moistur}}{kg\ wet\ solid} * 100$

2.2.2 Equilibrium Moisture Content (X*)

This is the moisture content of a substance when at equilibrium with a given partial pressure of the vapor. Suppose that a wet solid is brought into contact with a stream of air of constant temperature and humidity in such amount that the properties of the air stream remains constant and that the exposure is sufficiently long for equilibrium to be reached. In such a case the solid will reach a definite moisture content that will be unchanged by further exposure to this same air. This is known as the equilibrium moisture content of the material under the specified condition.

2.2.3 Moisture Ratio (M_R)

A moisture ratio is a ratio that compares the mass or volume of air to the mass or volume of moisture contained in that air.

2.2.4 Drying Rate

In air drying, the rate of removal of water depends on the conditions of the air, the properties of the food and design of the dryer.

2.3 Drying Kinetics:

Kazarian[(1)] experimentally observed that the results of numerical solutions are compared with experimental data for wheat grains. In the experiments, temperature at different elevations, humidity of the exit air, fluidization velocity and moisture content of particles at different times are measured. It is found that the drying of grain materials is usually controlled by internal mass transfer parameters. The initial moisture content of the bed materials can have an important effect on the drying rate depending on the physical properties of bed materials. For simplicity of the numerical solution the wheat kernel is assumed to be spherical with an average diameter of 3.66 mm and density of 1215 kg m^{-3}.

The moisture content, M_C is given by

$$M_C = \left(W_b - W_d\right)/W_d \tag{1}$$

Where M_C is moisture content of sample.

Hii et al.[(2)] investigated that the cocoa drying kinetics and compare the quality of the dried beans produced from sun and artificial using natural sun light and by hot air inside an air ventilated oven at air temperatures of 60 °C ,70 °C and 80 °C . Only falling rate drying periods were observed in the oven drying treatments at the drying temperatures tested. The drying rates were calculated based on the following Eq^n. as:

$$K = \frac{W_i - W_f}{t} \tag{2}$$

Ibrahim et al. [(3)] experimentally were conducted to examine the effect of drying air temperature and humidity on the drying kinetics. A model to estimates the drying behavior of Lemon grass was developed. The experiments were carried out in a constant temperature and humidity chamber. The increase in the drying air temperature increased the drying process and decreased the equilibrium moisture content (EMC) of Lemon grass. The air humidity was found to have an adverse effect on the drying process. The drying process decreased as the air humidity increases. The effect was less than that of the temperature. The EMC have high values with high relative humidities. Semi-theoretical thin layer drying models were used widely in the analysis of drying characteristics. The moisture ratio (M_R) can be calculated as:

$$M_R = \frac{(M - M_e)}{M_o - M_e} \tag{3}$$

Where: MR is the dimensionless moisture ratio, M_t is the moisture content at time t, and M_o and M_e are the initial and equilibrium moisture contents, respectively, on dry basis.

2.4 Estimation of Moisture Diffusivity

2.4.1 Diffusion:

Diffusion is a characteristic behavior of drying materials where drying or water vapour transfer rates inside the material are controlled by diffusion towards the outer surface. Then, the water vapour concentration on the outer surface of the material becomes very close to equilibrium values. Moisture content increases as a result of increasing equilibrium concentration of the water vapour on the surface of the material at higher temperatures.

Fick's diffusion equation for particles is used for calculation of effective moisture diffusivity. Since the mushrooms are dried after slicing, the diffusivity [4] of the samples is calculated as follows.

$$M_R = \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff} t}{r^2} \right) \tag{4}$$

Where: D_{eff} is the effective diffusivity in $m^2\ s^{-1}$, t is the time of drying in seconds, and r is the slab thickness in centimeters

Amiri Chayjan et al., They have used similar type of equation for diffusivity [5] which as follows

$$M_R = \frac{6}{\pi^2} \exp\left(\frac{\pi^2 D_{eff} t}{r^2} \right) \tag{5}$$

2.4.2 Activation energy (E_a)

The activation energy (E_a) interpreted as the minimum energy that must be supplied to break water-solid or water-water interactions, and to move the water molecules from one point to another in the solid. The smaller E_a value of the sample indicates that water molecule can more readily move in the sample. The activation energy required for drying was calculated by using the Arrhenius equation.

$$\ln(D_{eff}) = \ln(D_o) - \frac{E_a}{R}\frac{1}{T} \tag{6}$$

Where: D_{eff} is the effective moisture diffusivity (m^2s^{-1}), D_o is the constant (measured as intercept at y axis from the plot of D_{eff} vs Ea), Ea is the activation energy (kJ mol^{-1}), R is the universal gas constant (8.314 kJ $mol^{-1}\ K^{-1}$), T is the absolute temperature (K).

Kossovich and Lebedev[6] formulated the mechanism of moisture transport in the drying of heat sensitive materials in the fluidized bed dryer. Fulford[7] Constructed Drying-rate curves were constructed and used them the calculation of critical moisture content, drying constant, effective diffusivity of moisture through the slices and energy of activation for diffusion. They attempted to correlate the process of moisture removal to the process of rehydration. A possible diffusion mechanism based on the concept of internal and external resistances has also been discussed by them.

Ginzburg[8] have expressed simplified mathematical models of heat and mass transfer in a fluidized bed dryer where deactivation kinetics of biosynthesis products during drying is utilized. The effect of longitudinal dispersion on the process and results of fluidized bed drying in a continuous system have also been analyzed by them.

Hallstron et al. [9] studied the drying characteristics for granular compounds of mono calcium phosphate fertilizer. Tulasidas et al. [10] studied the drying kinetics of shelled corn in spouted bed dryer equipped with draft plates. Bilgin et al. [11] obtained generalized drying curves for predicting drying times of porous solids in the falling rate period in rotary dryer. Anantharaman and Sundharam[12] studied the drying characteristics of Ragi seeds by fluidized bed infrared drying technique.

Simmonds et al. [13] experimentally investigated the drying of granular products in a circulating dryer and found that the rate of drying is independent of the air velocity in the range of 1.64m/s to 8.74 m/s. The rate of drying was proportional to the free moisture content of the grain, while the grain temperature was related to the moisture content at any stage of the drying process.

Chandran et al. [14] compared the performance of batch and continuous spiral fluidized bed systems with an ion exchange resin and sand at 105°C. They found that for certain drying time, batch operations give lower average moisture content.

Abid et al. [15] performed an experimental and theoretical analysis on the mechanism of heat and mass transfer during the drying of corn kernels in a fluidized bed dryer. They found that the velocity of the gas and the external conditions, such as the humidity, had only a small effect on the rate of drying.

Thomas and Varma[16] experimentally investigated fluidized bed drying of granular cellular materials and compared the experimental results of batch and continuous fluidized bed drying carried out at different conditions (viz. temperature, flow rate of the heating medium, particle size and mass of solids in the bed.

Watano et al. [17] experimentally studied the drying of wet granules in an agitating tapered fluidized bed type dryer. The effects of the operating conditions on the properties of the granules were investigated. They also examined the relationships between the operating conditions and the drying rates. It was concluded that slow rotational speed, large air velocity and high air temperature should be selected in order to increase the drying rate.

Gaston et al. [18] observed that the moisture diffusion coefficient of wheat is dependent only on temperature. Efficiency is found to be high at the initial stage of the drying process due to rapid evaporation of the surface moisture of the kernels. But it decreases exponentially during the drying from inside the kernels until the end of the drying process.

Chalida and Sakamon [(19)] experimentally studied the effects of various operating parameters, i.e., the values and patterns of inlet air velocity and temperature, on the drying kinetics and some selected quality of dried coconut viz. color and surface oil content were then examined.

Krokida et al. [(20)] studied the drying kinetics and drying constant in various foods. The results of more than 35 food materials classified in eight categories have been discussed by them. The results concerned the reported range of variation of drying constant data together with the corresponded range of variation of air temperature, humidity, velocity and material size. They have related drying constant to air temperature, humidity, velocity and material size, using a simple empirical model. Simpson[(21)] observed that the drying rate increased with air velocity for moisture contents above approximately 40% to 50% and the drying rate gradually decreased and tended to level off with air velocities above 3.05 to 3.56 m/s and moisture contents below approximately 80% to 90%.

Ndukwu[(22)] experimentally investigated the effect of some drying parameters and drying conditions of cocoa bean. Three levels of temperatures (55°C, 70°C and 81°C) and three air velocity levels (1.3, 2.51 and 3.7 m/s) were used in the work. General observation was that the drying rate increases with drying temperature and air velocity but decreases with time at the same drying temperature. The optimum drying constant and drying rate, which gave the desired result, was chosen based on the drying temperature and drying air velocity.

Amin et al. [(23)] experimentally investigated convective drying in a laboratory scale. Experiments were performed at different air temperatures and a constant air velocity of 2 m/s. It was observed by the authors that Logarithmic model out of 12 different thin layer drying models could satisfactorily illustrate the drying curve of bell pepper The high values of coefficient of determination and the low values of reduced chi-square and root mean square error indicated that the Logarithmic models were satisfactorily to describe the drying behavior of bell pepper. The moisture diffusion coefficient was found to be varied between 1.7×10^{-9} and 11.9×10^{-9} m^2/s using Fick's second law for the given temperature range and corresponding activation energy was found to be 44.49 kJ/mol.

Hii et al. [3] developed theoretical modeling on the drying kinetics using Fick's law of diffusion and determined the effective diffusivity values. Reasonable values of the coefficient of determination were obtained from the plot of the experimental and predicted moisture ratio data. Estimated effective diffusivities were ranged from $4.57 \text{ X } 10^{-11}$ m^2s^{-1} to $4.84 \text{ X } 10^{-10}$ m^2s^{-1}.

Srinivasakannan and Balasubramanian[24] studied the drying kinetics corresponding to the falling rate period and modeled it using Fick's diffusion equation in fluidized beds. The estimated diffusion coefficient is normally the single kinetic parameter to assess the kinetics of the drying and is often used to compare the drying kinetics in different forms of drying. The dependence of the diffusion coefficient on the temperature and the concentration is well understood from the basic concepts of mass transfer; however, the diffusion coefficient estimated using Fick's diffusion model is found to vary with additional variables such as the solids holdup. The estimated diffusion coefficient is found to vary by orders of magnitude with the variation in the column diameter (solids holdup), necessitating the caution one needs to observe while comparing the kinetics of fluidized beds based on the diffusion coefficient.

Walde et al.[25] experimentally investigated dehydration of button mushrooms and oyster mushrooms varying various pretreatments like blanching, blanching followed by soaking in potassium metabisulphite, fermented whey, curds, etc. they also dried the mushrooms in different dryers viz, hot air cabinet dryer, fluidized bed dryer, vacuum dryer and microwave oven. The drying times were less in case of oyster mushrooms (7200 – 8100 s) compared to button mushroom (8700 – 10800 s) with cabinet drying. The diffusion coefficients evaluated were also found in the same order. In case of oyster mushroom, the diffusion coefficients are found to be maximum for the whey treated microwave dried mushroom and minimum for the control cabinet tray dried sample. The diffusion coefficients for the blanched button mushrooms are found to be maximum for microwave drying and minimum for vacuum oven drying.

Chandrasekar[26] observed that the drying rate increases significantly with increase in temperature and flow rate of the heating medium, however it decreases with increase in solids holdup. The duration of constant rate periods was found to be insignificant considering the total duration of drying. The experimental data have also been modeled using fundamental Fick's diffusion equation where the effective diffusivity coefficients were estimated. The estimated effective diffusion coefficients have also been compared with the reported literature on effective diffusion coefficient for other grains and found to be within the same order of magnitude.

Mirzaeel et al. [27] experimentally studied the Fick's second law which has been used as a major equation to calculate the moisture diffusivity for apricot fruit with some simplification. They carried out drying experiments at different air temperatures and different the drying air velocities. Only a falling drying rate period was observed from the drying curves. The calculated value of the moisture diffusivity was varied from 1.7×10^{-10} to 1.15×10^{-9} m^2/s for apricot fruit and the value of activation energy ranged from 29.35 to 33.78 kJ/mol at different velocities of air.

Nwabanne[28] attempted to provide data on the engineering properties such as moisture content, specific heat capacity, thermal conductivity, thermal diffusivity and bulk density. Equally the drying rate is a function of the chemical composition of the cultivars. The drying time is a function of the moisture content. Bulk density, specific heat capacity, and thermal conductivity increased with increase in moisture content while thermal diffusivity decreased as moisture content increased.

Meisami-asl et al. [29] experimentally determined the coefficients used in drying models which are essential to predict the drying behaviour. Their studies were conducted to compute effective moisture diffusivity and activation energy of samples of apple slices. The thin-layer drying experiments were carried out under different air temperatures and different air velocities and different slices of apple were used at constant air humidity of 21%. Results indicated that drying takes place in the falling rate period. An Arrhenius relation with an activation energy value of 22664.1 to 30919.0 J/mol and the diffusivity constant value of 1.16×10^{-4} to 6.34×10^{-3} m^2/S were obtained which shows the effect of drying air temperature, air velocity and slice thickness on the diffusivity.

Hatamipour and Mowla[30] investigated the variations of drying material density, size and mass diffusivity with change of moisture content. It is found that, air temperature, inert material, and air velocity had no significant effect on physical properties and therefore, shrinkage and density are only functions of moisture content, but diffusivity is a function of temperature and moisture content. Based on the experimental data obtained, some correlations developed for variation of shrinkage, density and diffusivity of green peas and maize during drying in a fluidized bed with inert particles.

Supawan et al. [31] studied the effective moisture diffusivity in form of Arrhenius type equation, which is used for predicting the mathematical model for the drying kinetics. A good agreement has been observed between the calculated and the experimental data. The simulated results of energy indicates that low potential of drying occurs at the low inlet drying air temperature and low initial moisture content whilst the drying with high inlet drying air temperature and high initial moisture content have a high potential.

Ademiluyi et al. [32] experimentally investigated drying kinetics of three popcorn varieties (Pin, Deep and Light yellow). The popcorn kernels initially conditioned to 25% moisture content were dried in a bench scale rotary drier to 14% moisture content at various air flow rates and temperatures. Falling rate drying period was observed for the three popcorn varieties with Pin popcorn having the highest drying rate. Falling rate period was exhibited with the three popcorn varieties at different temperatures and airflow velocities. Hence, it can be conducted that the moisture movements in the kernels were diffusion controlled. The three popcorn varieties when dried at the same condition had different drying times.

Hassini et al. [33] investigated the two different methods and applied them to evaluate the diffusion coefficient. The first one was based on the analytical solution of a fickian diffusive model which enabled diffusivity determination by simple linear regression over experimental data. The regression was done using the real sample thickness in order to account for shrinkage. The second one was based on a numerical solution of solid mass balance equation and moisture transfer diffusion/convection equation, these equations being coupled by the solid phase velocity due to shrinkage. At each time step of the simulation, the diffusivity were adjusted to minimize the difference between calculated and measured sample mean moisture content. Due to several simplifying hypothesis the first method could only provide approximate results, while the second could be considered as reference. Predictive correlations for moisture diffusivity as function of temperature and moisture content are presented As follows Eq^n.

$$\frac{X}{X_O} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)} \exp\left[-(2n+1)^2 \frac{\pi^2}{4} \frac{Dt}{L^2} \right] \tag{7}$$

Mustafa et al. (34) conducted thin- layer drying experiments were conducted to examine the effect of drying air temperature and humidity on the drying kinetics. Four different thin-layer drying models were compared with each other with respect to their coefficient of determination, Mean Bias Error (MBE) and Root Mean Square Error (RMSE). The one with highest (R^2) and lowest (MBE) and (RMSE) was selected to better estimate the drying curves. Three different temperatures and three different humidities were studied with a fixed air velocity. The increase in the drying air temperature increased the drying process and decreased the Equilibrium Moisture Content (EMC) of Lemon grass. The drying process decreased as the air humidity increases. The effect was less than that of the temperature as the EMC have high values with high relative humidity.

Zbey and Soylemez(35) studied batch drying of wheat grains in a fluidized bed dryer, which had a swirling flow field in its drying medium. The effects of the swirling flow field on the drying performance were investigated by using an axial guide vane type swirl generator. The effects of the mass flow rate and temperature of the air on the drying performance were also investigated.

2.5 Artificial Neural Network

As an alternative to these parametric models, the use of Artificial Neural Networks stands out. They have aroused great interest in recent years because of their ability to efficiently correlate nonlinear multidimensional spaces. Among the simulation techniques, Artificial Neural Networks (ANNs) have high learning ability and capability of identifying and modeling the complex non-linear relationships between the input and the output of a system. Drying is quite complex and uncertain and they can be considered as non-linear, time-varying process functions of many unknown factors. This phenomenon has been modeled with different levels of complexity.

Hence, the potential of Artificial Neural Networks as universal approximates can be explored and their usefulness in predicting the values of process performance variables from independent variables based on experimental data for continuous fluidized bed dryer can be studied. For complex processes like fluidized bed drying, neural networks perform better than empirical models with noisy or incomplete information.

The differences for all of the proposed ANN structures in input layer and the relations of the hidden layers. The available data set is divided into two parts one corresponding to training and the other corresponding to validation of the model or testing. The purpose of training is to determine the set of connection weights and nodal thresholds that cause the ANN to estimate outputs that are sufficiently close to target values. The complete data to be employed for training should contain sufficient patterns so that the networks can establish under-laying relationship between input and output variables. During training, those are adjusted based on the error or difference between ANN output and target responses.

Artificial Neural Network (ANN) have shown increased ability for solving non-linear prediction problems in the field of food processing Neural networks are useful when no exact mathematical information is available Artificial neural network are mathematical models of biological neural systems. During last few years, interest in using Artificial Neural Networks (ANN) as a modeling tool in food technology has increased. ANN have been successfully used in several food processing applications like model for prediction of drying rates, physical properties of dried carrot, prediction of dryer performance, extrusion processing of wheat and wheat-black soybean, energy requirements for size reduction of wheat, grain drying process.

ANN has been applied to a fluidized-bed dryer to predict the moisture and temperature of the product the moisture content parameter in grain drying using ANN with different numbers of hidden neurons for different samples were predicted the results obtained from ANN to predict moisture content at different temperature values during drying were compared with the experimental data to confirm the validity of the simulation results. Inlet and outlet air temperature, absolute humidity and air flow have been used as the input variables to the layers of the ANN. The moisture content obtained of the solid from drying operation was predicted, modeled and the fluidized-bed drying process was optimized using an ANN structure with three layers, four inputs, four hidden neurons, and one output.

2.5.1 Back Propagation Neural Network

Back-propagation is a systematic method of training of multilayer neural networks. It is built on high mathematical foundation and has very good application potential. Even though it has own limitations, it is applied to a wide range of practical problems and has successfully demonstrated its power. The back propagation refers to the fact that any mistakes made by the network during training sent backwards through it in an attempt to correct it and so teach the network what's right and wrong. This BPN uses the gradient descent learning method, which represents the error function as it tries to find the minimum of the error function and by doing so decrease the error. Back propagation learns by iterative processing of a set of training data (samples). For each sample, weights are modified to minimize the error between network's classification and actual classification.

The errors for the units of the hidden layer are determined by back propagation of units of the output layer. This method is called Back-propagation learning rules. Back-propagation can also be generalization of the delta rule for non-linear activation functions and multi-layer networks. A Back-propagation network consists of at least three layers:

- an input layer
- at least one intermediate hidden layer
- an output layer

Schematic representation of ANN-Structure has been shown below in Fig. - 1.

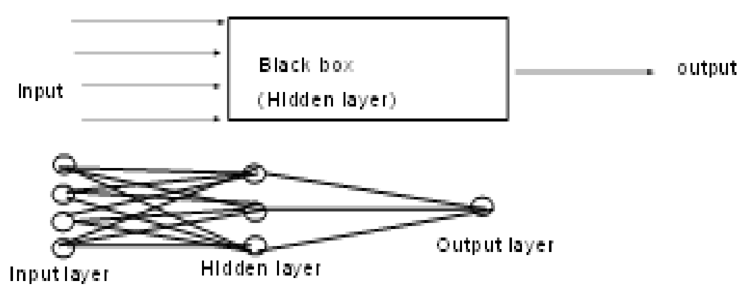


Fig. - 1: Schematic representation of ANN-Structure

2.5.2 Advantages of Neural Network:

- A neural network can perform tasks that a linear program cannot.
- When an element of the neural network fails, it can continue without any problem by their parallel nature.
- A neural network learns and does not need to be reprogrammed.
- It can be implemented in any application.
- It can be implemented without any problem.

Artificial neural network – approach in short:

- ANN-model is used in the Supervised Learning framework.
- A three-layered feed forward Neural Network is used.
- The network is trained for a given set of input and target data sets.
- The used sigmoidal activation function in the present report is expressed as follows :

$$f(x) = 2.0 \times \left(\frac{1}{1+e^{-\lambda.x}} - 0.5 \right)$$

Satish and Setty[36] experimented on drying of solids in a continuous fluidized bed dryer with different variables like bed temperature, gas flow rate, solids flow rate and initial moisture content of solids. The data are modeled using artificial neural networks. The results obtained from artificial neural networks are compared with those obtained using Tanks-in-series model. It is found that results obtained from ANN fit the experimental data more accurately compared to the RTD model with less percentage error. This indicates a better of artificial neural networks to experimental data compared to various mathematical models.

Nazghelichi et al. [37] used static and recurrent artificial neural networks (ANNs) to predict the drying kinetics of carrot cubes during fluidized bed drying. Static ANN were used to correlate the outputs (moisture ratio and drying rate) to the four exogenous inputs (drying time, drying air temperature, carrot cubes size, and bed depth). In the recurrent ANNs, in addition to the four exogenous inputs, two state input and output (moisture ratio or drying rate) were applied. A number of hidden neurons and training epoch were investigated in this study.

Amiri et al.[38] determined the thermo-physical characteristics of pistachio which is thermal conductivity which is predicted at a range of temperatures (50 to 95°C) and moisture contents (3.8 to 52.15% dry basis; d.b.) using line heat source method and Artificial Neural Networks

(ANNs). Two independent variables i.e. temperature and moisture content were considered as inputs of ANNs and thermal conductivity were considered as an output variable. Decreasing moisture content reduced thermal conductivity, but decreasing it further caused proportionate increase in thermal conductivity of the samples. They observed that Prediction accuracy of thermal conductivity by designed ANN is better than statistical results.

Tiwari and Pandey[(39)] Modeled the high velocity hot air recirculatory tray drying of treated and untreated sweet pepper slices which were carried out using artificial neural network and response surface methodology. Drying air temperature, drying air velocity and slice sizes were considered as the independent variables where drying rate, moisture ratio during drying, the rehydration ratio and sensory quality of the dried slices were measured as the dependent variables. The models obtained were compared and it is observed the ANN model was best suitable to predict the dependent responses as compared to the RSM model.

Shrivastav & Kumbhar[(40)] determined the drying characteristics, the analytical model and development of Artificial Neural Network (ANN) models at low pressure superheated steam drying were studied. Effects of steam temperature and pressure on drying rates were determined. Second degree polynomial, non linear regression analysis resulted in a good agreement of defined model by changing the values of temperature and corresponding pressure. Optimized ANN models were developed for all data set. The correlation coefficient for all data set was >0.98 in all cases.

Marius et al. [(41)] an developed Artificial Neural Network (ANN) modeling of gas drying by adsorption in fixed bed of composite materials. The experimental investigations were carried out at two values of relative humidity and three values of air flow rate respectively. The experimental data were employed in the design of the feed forward neural networks for modeling the evolution in time of some adsorption parameters, such as adsorption rate, water concentration in the bed, water vapor concentration in air at the exit from the fixed bed, drying degree and rate respectively.

Koni et al. [(42)] investigated the drying of baker's yeast in a fluidized-bed dryer. Mathematical modeling of the process was carried out, incorporating the important process and quality parameters of the system. Artificial neural network (ANN) and adaptive neural network-based fuzzy inference system (ANFIS) structures were used to create process and quality models. ANN quality modelings were performed using process output parameters and the quality losses incurred from drying the product were determined.

Menlik[(43)] used the freeze drying process based on different parameters, such as drying time, pressure, sample thickness, chamber temperature, sample temperature and relative humidity. An artificial neural networks model has been developed for the prediction of drying behaviors, such as M_C and M_R of strawberries in the freeze drying process. Zhang and Yang[(44)] used Artificial Neural Networks (ANN) developed for modeling of rough rice drying. The ANN outputs were the six performance indices: energy consumption (EC), kernel cracking (KC), final moisture content (FMC), moisture removal rate (MRR), drying intensity (DI) and water mass removal rate (WMRR) and the inputs were the four drying parameters: rice layer thickness (RLT), hot airflow rate (HAR), hot air temperature (THA) and drying time (TD). The optimal model was a four-layered back-propagation neural network with 8 and 5 neurons in the first and the second hidden layers respectively. The effectiveness of the proposed model was demonstrated using experimental data.

Khoshhal et al. [45] used Artificial Neural Network (ANN) modeling and several mathematical models were applied to predict the moisture ratio in an apple drying process. Four drying mathematical models were fitted to the data obtained from eight drying runs and the most accurate model was selected. Two sets of ANN modeling were also performed. In the first set, the data obtained from each pilot were modeled individually to compare the ANN predictions with the best mathematical model. In the second set of ANN modeling, the simultaneous effect of all the four input parameters including air velocity, air temperature, the thickness of apple slices and drying time were investigated. The results showed that the ANN predictions were more accurate in comparison with the best fitted mathematical model. In addition, none of the mathematical models were able to predict the effect of the four input parameters simultaneously, while the presented ANN model predicts this effect with a good precision.

CHAPTER III

Experimental Aspects

A fluidized bed dryer as shown in Fig.-2 has been used for the present study. Different materials mainly grains and vegetables have been used to study their drying kinetics. It was aimed to study the effect of different system parameters on drying kinetics of materials in a fluidized bed dryer. Different system parameters studied in the present work are listed in Table-1 as scope of the work.

Fig. - 2 Fluidized bed dryer (Laboratory set up)

3.1 Raw Material and Method

The fluidized bed dryer is connected to a heat pump dehumidifier system. The drying conditions was set by the temperature controller in the heat pump dehumidifier system, by setting at different temperature the drying set-up was run for 10 minutes to achieve steady state conditions of drying before material introduction. The hot air velocity passing through the material bed was maintained at a particular value of a velocity constant for a single set experiment. Samples were taken out at a regular interval of 10 minutes from the dryer for measuring the weight. Moisture content was determined by the different in weight.

3.2 Experimental set up

The line diagram for the experimental unit is shown in Fig.-3.

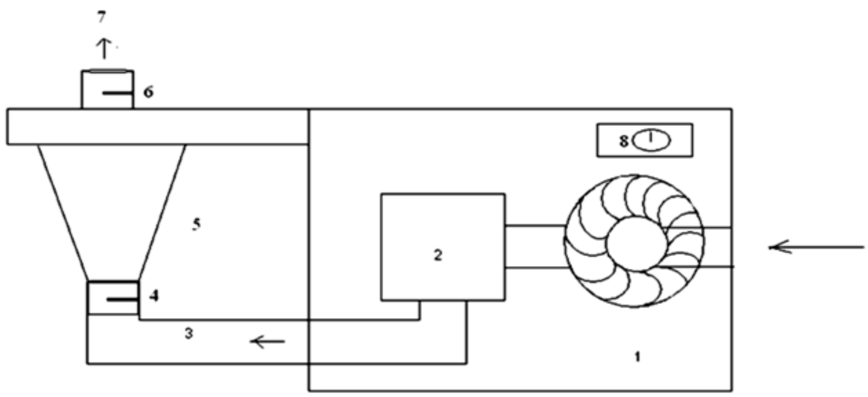


Fig. - 3: Schematic diagram of the experimental unit.

1. Air Compressor, 2.Heater, 3.Air inlet to the bed, 4.Inlet air temperature sensor, 5.Tapered Fluidized Bed, 6.Outlet Hot Air Temperature Sensor, 7.Hot Air outlet and 8.Timer.

Fresh air is sucked in and heated through the heater up to the desire value as set by the temperature sensor. Hot air enters the bottom of the fluidizer in which known amount of material is already taken for drying. Time of drying and flow rate of air is set before allowing the air to pass through the dryer. After each time of drying the material is taken out and weighted. The difference in weight indicates the amount of moisture lost during drying.

3.3 Parts of the experimental set up:

Experimental set up consist of different parts are -

3.3.1 Tapered Fluidized Bed Dryer

The bed is shaped like a truncated cone with bottom diameter is 12.1 cm where as the top diameter is 21.96 cm. The dryer height is 20 cm. The tapered angle is 14°.

The gas distributor was 2 mm thick with 2 mm perforations. A fine wire mesh of 0.2 mm openings was spot welded over the distributor plate to arrest the flow of solids from the fluidized bed into the air chamber. Air from the blower was heated and fed into the air chamber and into the fluidization column. The electrical heater consisted of multiple heating elements of 2 KW rating. The timer is provided in which time can be maintained from 0 - 50 min.

3.3.2 Temperature controller

A temperature controller, provided to the air chamber, facilitated the control of air temperature to ± 0.5 °C, for the operating range of 40 °C -110 °C.

3.3.3 Air movement

The selection and sizing of a fan to move air through a dryer is very important. The major resistance to the flow of air comes from the grain bed. The pressure drop through the bed support is of lesser effect, particularly for deep beds. The pressure drop across a grain bed is a function of the air velocity and the grain itself.

3.4 Experimental Procedure

The experimental is carried out batch wise. In the present work a batch fluidized bed dryer has been studied to analyze the drying characteristics of different grains, vegetables and mushrooms in terms of moisture content and diffusivity. Attempt has been made to study the effect of different system parameters (viz. drying air temperature, drying time, density of materials, and air velocity) on drying characteristics. Initial moisture content of the sample is determined as percentage by weight difference with the help of a moisture analyzer. A weighed amount of sample is taken in the dryer. Time, temperature and velocity are set then the power supplied to the unit by switching on. As the drying operation gets over the material is taken out and weighed. The difference in weight gives the idea of moisture loss content.

3.5 Analysis using Artificial Neural Network

The feed forward back propagation three layered ANN has been used in the present study to validate the developed correlation for drying kinetics on the basis of dimension analysis. The three layers in ANN are known as input, hidden and output. The input layer has five nodes, representing drying time (t), temperature (θ), velocity (U_o), density (ρ) or L/D ratio and moisture content or diffusivity of inlet air. The output layer has six nodes: a, b, c, d, K and n. From the experimental data, one data set is randomly selected as testing set and another four data sets prepared by manipulation were used for training. Network performances were evaluated by comparing the ANN - training output against those of the testing data and analyzing the root mean square (RMS) error between the normalized and experimental data over 5000 to 20000 number of epoches or cycles. The numbers of neurons in this hidden layer were varied to find the architecture that provides the least error and thereby the optimum ANN - structure is determined.

The different ANN-parameters for three layered, Back Error Propagation type network is given in Table-2. The optimum ANN – structure is shown in Fig.-4.

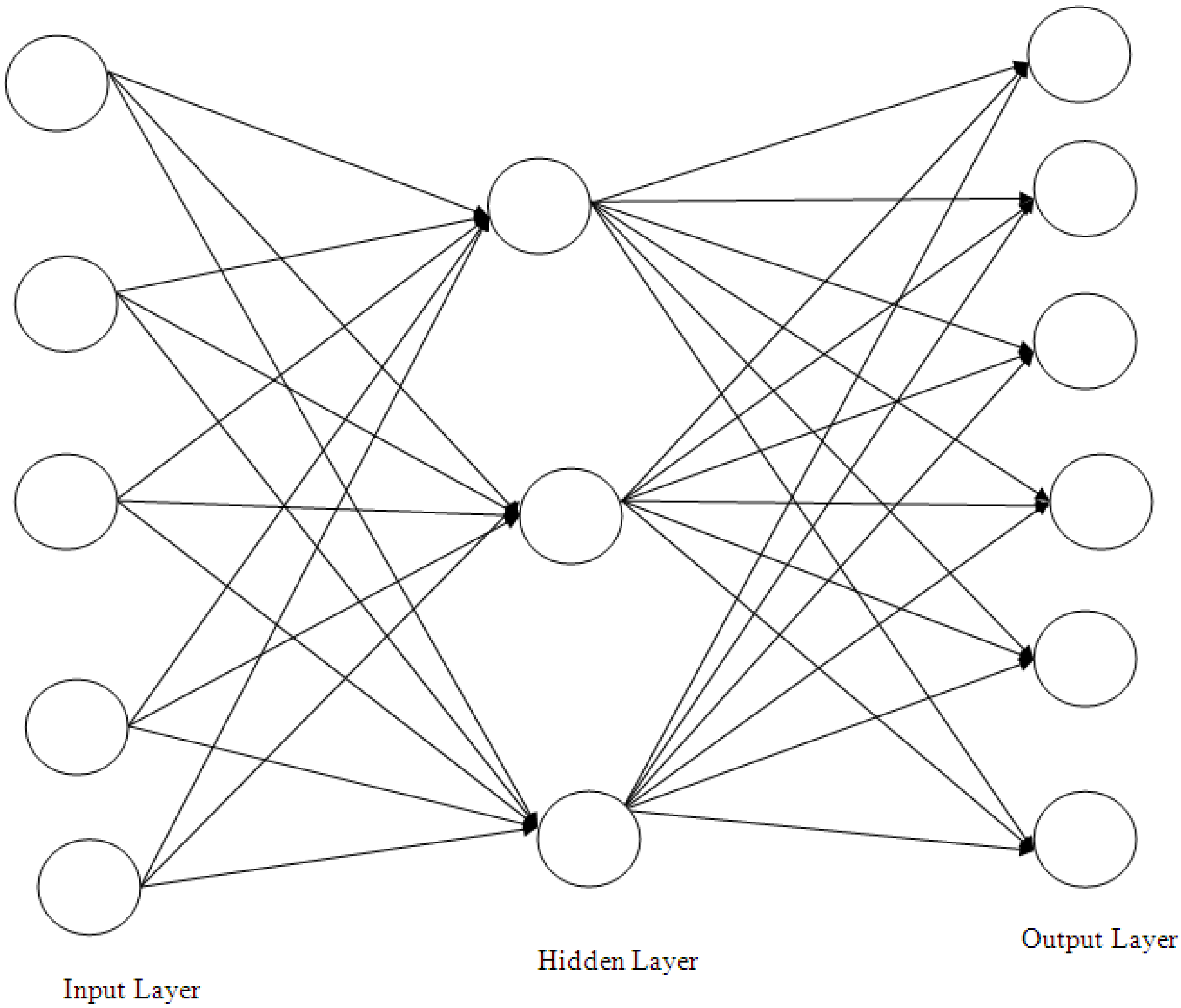


Fig. - 4: Optimum ANN – structure

Table - 1: Scope of the experiment for the drying experiment

Sl No.	Materials used	ρ_s, kg/m3	L/D	t, min.	θ, °C	U_o, m/s
1	Moong	1230	__	10	60	3.800
2	Moong	1230	__	20	60	3.800
3	Moong	1230	__	30	60	3.800
4	Moong	1230	__	40	60	3.800
5	Moong	1230	__	50	60	3.800
6	Moong	1230	__	50	40	3.800
7	Moong	1230	__	50	50	3.800
8	Moong	1230	__	50	60	2.875
9	Moong	1230	__	50	60	1.950
10	Moong	1230	__	50	60	0.975
11	Wheat	1215	__	50	60	3.800
12	Mustard	1100	__	50	60	3.800
13	Rice	1357	__	50	60	3.800
14	Mushroom	__	0.628	50	50	3.800
15	Radish	__	0.89	50	50	3.800
16	Tunduli	__	1.2	50	50	3.800
17	Ladies fingure	__	1.6	50	50	3.800
18	Barbatti	__	5.2	50	50	3.800

Table - 2: Optimum ANN-parameters for three layered, Back Error Propagation type network

ANN-Parameters:	For M_C of grains	For M_C of vegetables	For $D_{eff.}$ of mushroom	For $D_{eff.}$ of vegetables
Slope parameter (λ)	0.95	0.95	0.95	0.95
Learning-rate (α)	0.001	0.001	0.001	0.001
Number of training vectors	64	68	72	68
Number of testing patterns	80	84	90	84
Maximum Cycles/ epochs	25000	20000	20000	20000
No. Input nodes	05	05	05	05
No. of hidden nodes	03	03	03	03
No. Output nodes	06	06	06	06

CHAPTER IV

Observations and Results

4.1 Introduction

Any vegetables or grains or food materials have some internal moisture content for which drying is essential so that these materials can be preserved for some days. Sometimes over drying may deteriorate the food value of the food materials. That is why knowledge of initial moisture content and exact amount of drying, required for preserving the food materials is essential. But it is difficult to quantify the drying process. Therefore attempt has been made to study the effect of different system parameters on drying so that drying process can be easily optimized which will save depletion of energy as well as food value of the material.

The drying process has been tried to be quantified from the knowledge of moisture content from the sample with time. Also knowledge of diffusivity in turn quantifies the drying process. Therefore attempt has been made to evaluate drying in terms of moisture content and diffusivity of the samples in the present work.

4.2 Analysis of Moisture Content

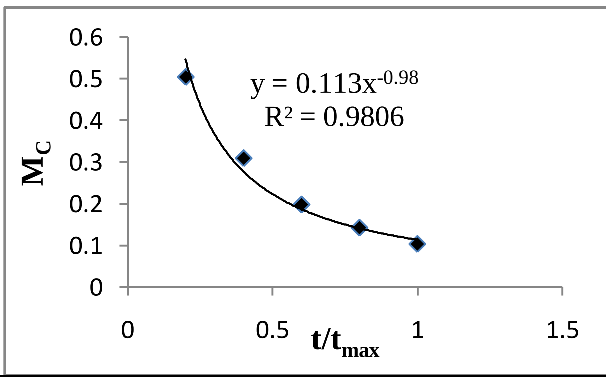
Different grains and vegetables were studied for analysis of loss in moisture content of the samples during drying operation. Moisture content gives information about the drying characteristics of the samples. Attempt has been made to develop expressions for the drying characteristics in terms of the moisture content of the sample on the basis of dimensionless analysis by correlating the experimentally observed moisture content of the sample against the different system parameters as follows.

For grains:

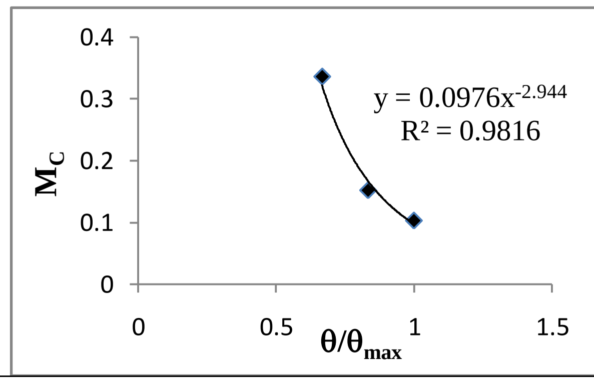
$$M_C = 15172 \times \left[\left(\frac{t}{t_{\max}} \right)^{-0.98} \left(\frac{\theta}{\theta_{\max}} \right)^{-2.944} \left(\frac{U_o}{U_{o\max}} \right)^{-0.453} \left(\frac{\rho_s}{\rho_f} \right)^{-1.65} \right]^{1.0232} \tag{8}$$

For vegetables:

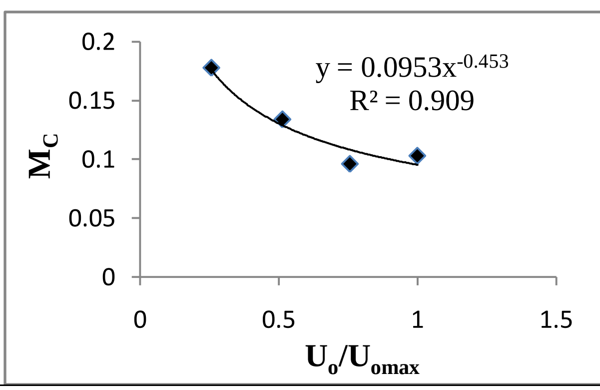
$$M_C = 121.1 \times \left[\left(\frac{t}{t_{\max}} \right)^{-0.07} \left(\frac{\theta}{\theta_{\max}} \right)^{-0.22} \left(\frac{U_o}{U_{o\max}} \right)^{-0.15} \left(\frac{L}{D} \right)^{-0.44} \right]^{1.1144} \tag{9}$$



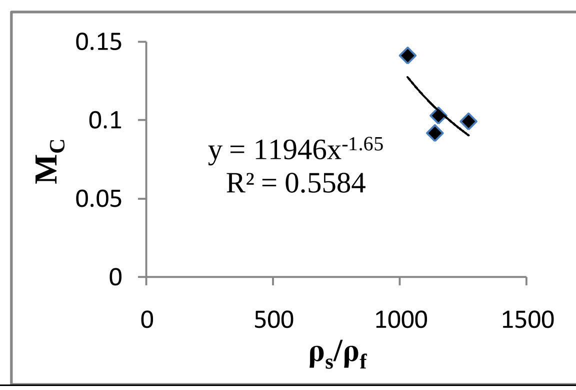
(A) Time versus Moisture Content



(B) Temperature versus Moisture Content

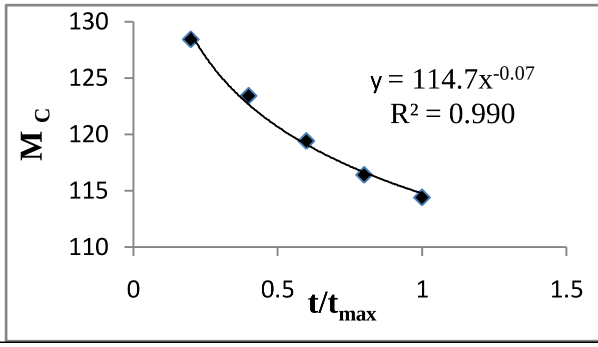


(C) Velocity versus Moisture Content

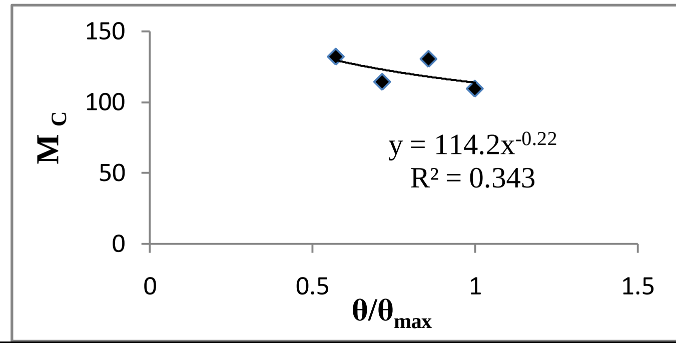


(D) Density of solid/density of air versus Moisture Content

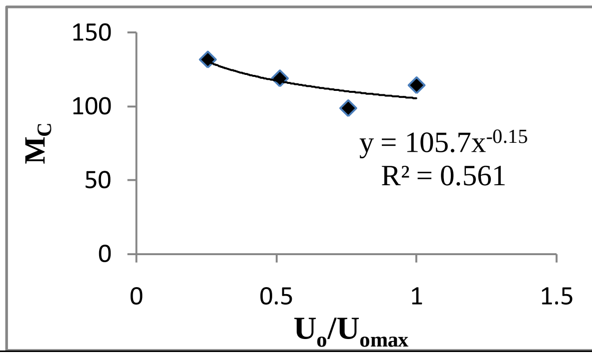
Fig.-5: Effect of individual system parameters on the loss in moisture content for grains



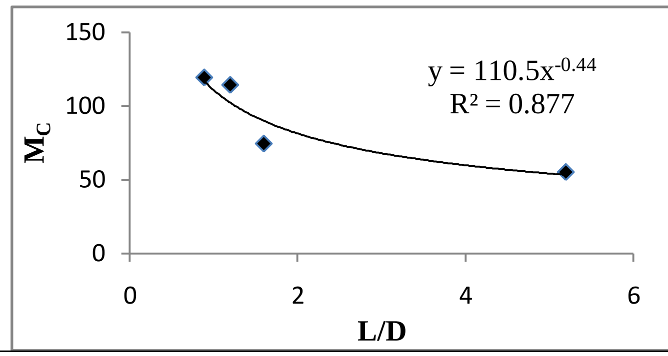
(A) Time versus Moisture Content



(B) Temperature versus Moisture Content



(C) Velocity versus Moisture Content



(D) Length/Diameter versus Moisture Content

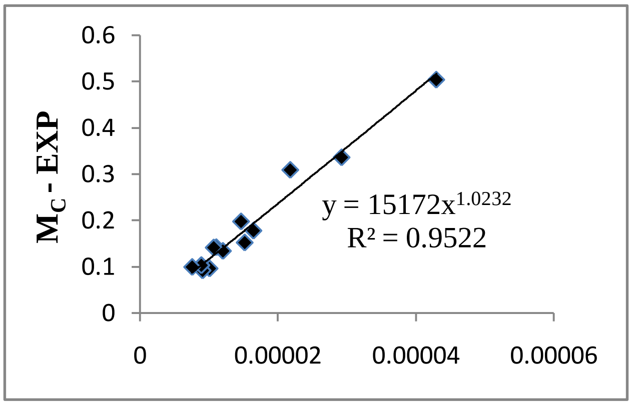
Fig.-6: Effect of individual system parameters on the loss in moisture content for vegetables

The effects of individual parameters on the moisture content of the samples are shown in Fig. - 5 and Fig. - 6 for grains and vegetables respectively.

As observed from the exponents of the correlation equations for the different system parameters (Fig.- 5 and Fig.- 6) moisture content of samples decreases with the decrease in each individual parameters for both the grains and vegetables indicating that drying (evaporation of moisture) of samples is directly related to each of these parameters.

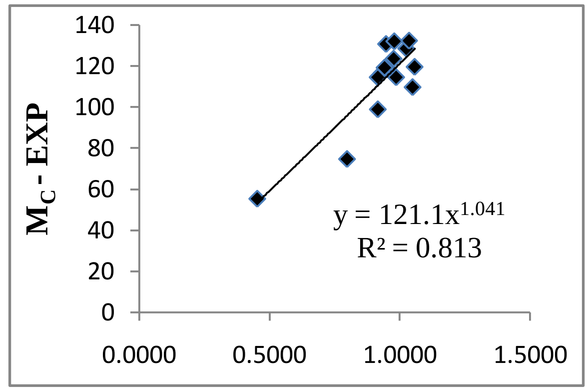
The correlation plot of moisture content against the system parameters for grains and vegetables are shown in Fig. - 7 and 8 respectively. It is also observed that moisture content of the sample decreases or drying increases with the system parameters.

In other words it can be said that the drying efficiency increases with increase in each of the system parameters (viz. drying time, temperature of drying, density of the material and fluid velocity) investigated for both grains and vegetables.



$(t/t_{max})^{-0.98} * (\theta/\theta_{max})^{-2.944} * (U_o/U_{omax})^{-0.453} * (\rho_s/\rho_f)^{-1.65}$

Fig -7: Correlation plot for the grains



$(t/t_{max})^{-0.07} * (\theta/\theta_{max})^{-0.22} * (U_o/U_{omax})^{-0.15} * (L/D)^{-0.445}$

Fig -8: Correlation plot for the vegetables

Fig.- 7 & 8: The correlation plot of moisture content against the system parameters for grains and vegetables

4.3 ANN Analysis for Moisture Content

The moisture content of the sample was also calculated using Artificial Neural Network. The developed correlations are as follows.

For grains:

$$M_C = 12190 \times \left[\left(\frac{t}{t_{max}} \right)^{0.93} \left(\frac{\theta}{\theta_{max}} \right)^{1.14} \left(\frac{U_o}{U_{omax}} \right)^{1.03} \left(\frac{\rho_s}{\rho_f} \right)^{1.03} \right]^{1.05} \tag{10}$$

For vegetables:

$$M_C = 103.99 \times \left[\left(\frac{t}{t_{\max}} \right)^{0.45} \left(\frac{\theta}{\theta_{\max}} \right)^{0.44} \left(\frac{U_o}{U_{o\max}} \right)^{0.44} \left(\frac{L}{D} \right)^{0.43} \right]^{0.51} \tag{11}$$

The calculated values thus obtained were compared against the experimentally observed values and root mean square (RMS) error was calculated. The plots of RMS error against the number of cycles or epoches for both the grains and vegetables are shown in Fig-: 9 and 10 respectively.

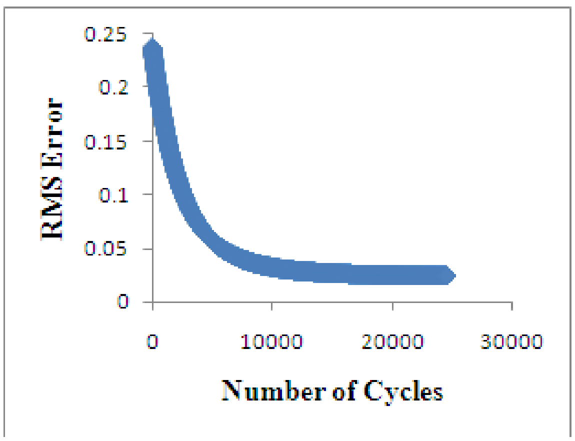


Fig -9 The RMS error plot for grains

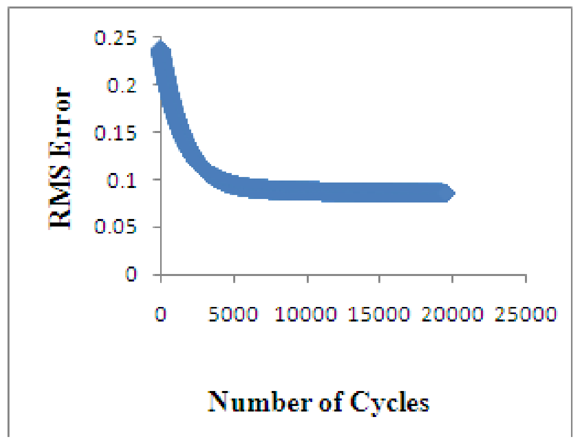


Fig -10: The RMS Error plot for vegetables

Fig.- 9 & 10: The plots of RMS error against the number of cycles for both the grains and vegetables

It is observed from the RMS error plot for grains that error changes from 0.24 at 5000 numbers of cycles to 0.02 at 25000 numbers of cycles. Error did not change further RMS error remained constant over 25000 numbers of cycles. This constant nature of error plot implies that the developed correlation using ANN analysis can also be used over a wide range of parameters.

In other words the developed correlation by dimensionless analysis is validated against the ANN analysis as the error is almost negligible. RMS error for vegetables started at 0.24 and decreased to 0.1 at 5000 number of cycles and which remained constant over 20000 cycles.

4.4 Analysis of Diffusivity

Attempt has been made to study the diffusivity of mushroom and different vegetables (viz. Radish, Tundli, Lady's finger and Barbatti, one type of Beans) dried through a fluidized bed drier in the present study. Fick's diffusion equation has been used for the calculation of effective moisture diffusivity of samples. Attempt has also been made to develop expressions for the drying characteristics in terms diffusivity of the sample by correlating the observed diffusivity of the sample with the different system parameters for both, the mushroom and vegetables.

The developed correlations are as given below.

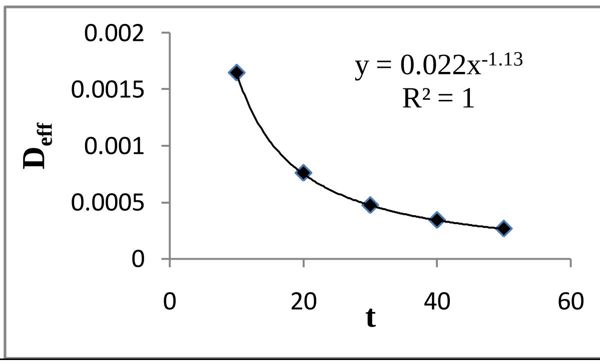
For Mushrooms:

$$D_{eff} = 0.013 \times \left[(t)^{-1.133} (\theta)^{-0.522} (U_o)^{0.109} \left(\frac{L}{D} \right)^{-3.357} \right]^{0.798} \tag{12}$$

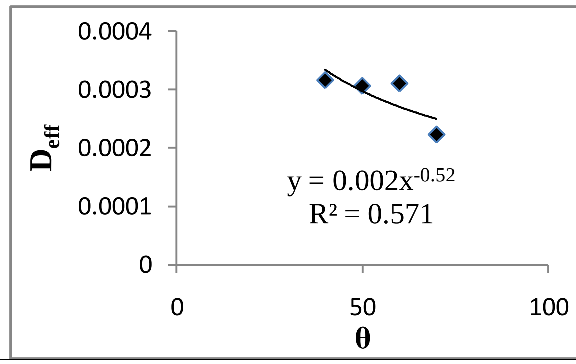
For Vegetables:

$$D_{eff} = 0.358 \times \left[(t)^{-1.339} (\theta)^{-0.729} (U_o)^{-0.354} \left(\frac{L}{D} \right)^{-2.651} \right]^{0.982} \tag{13}$$

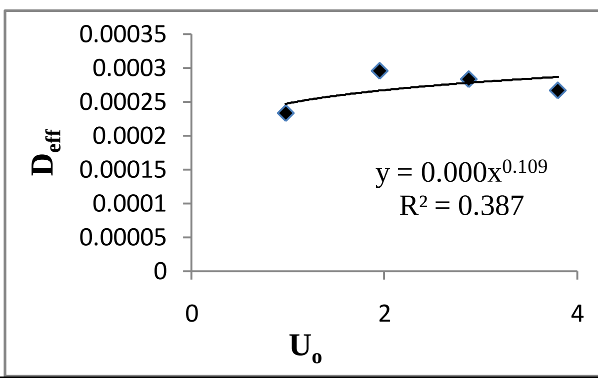
The effects of individual parameters on the diffusivity of the samples are shown in Fig. 11 & 12 for Mushroom and vegetables respectively. It is observed from the exponents of the correlation equations that increased velocity of the air increases the diffusivity of Mushroom (Fig.-11(C)) whereas all other parameters have inverse effects on diffusivity of the samples for both i.e. for mushrooms and vegetables. Increased velocity is also observed to decrease the diffusivity of the vegetables (Fig. -12 (C)).



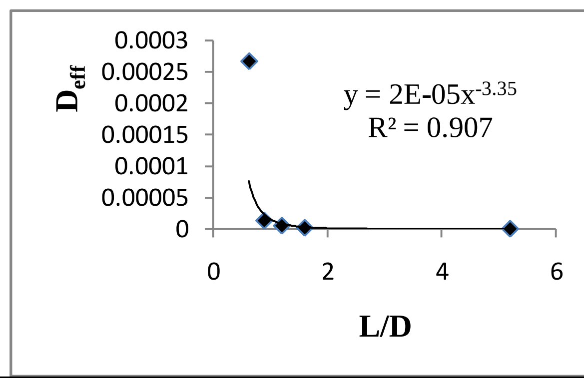
(A) Time versus Diffusivity



(B) Temperature versus Diffusivity

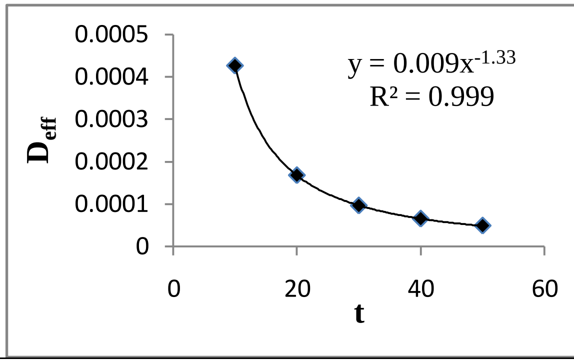


(C) Velocity versus Diffusivity

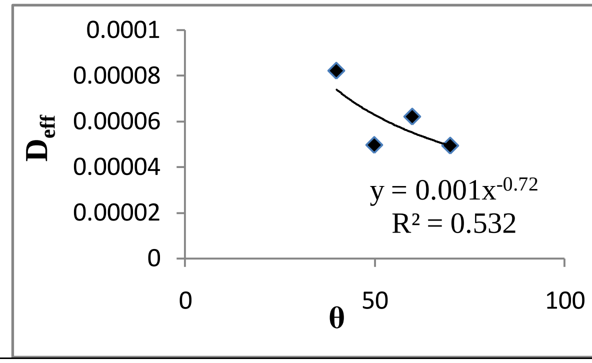


(D) Length/Diameter versus Diffusivity

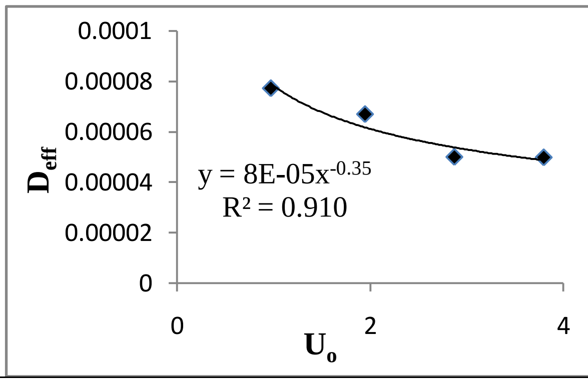
Fig.- 11: Effect of individual system parameter on the diffusivity of mushroom



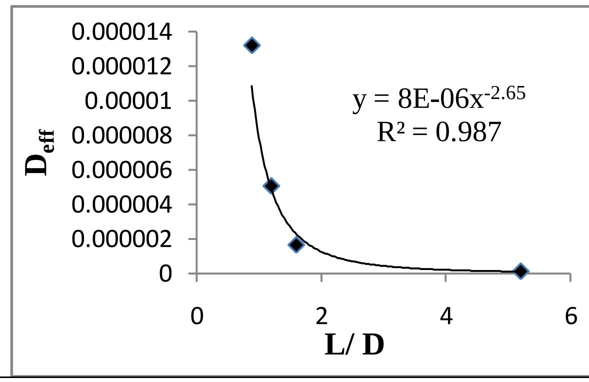
(A) Time versus Diffusivity



(B) Temperature versus Diffusivity



(C) Velocity versus Diffusivity



(D) Length/Diameter versus Diffusivity

Fig.- 12: Effect of individual system parameter on the diffusivity of vegetables

The correlation plots for diffusivity of the samples against the system parameters are shown in Fig. 13 & 14 for mushrooms and vegetables respectively. As a whole it is observed that the diffusivity of the samples increases with the increased variation of the system parameters as the overall exponents are found to be positive for both the cases, i.e. for Mushroom and vegetables studied.

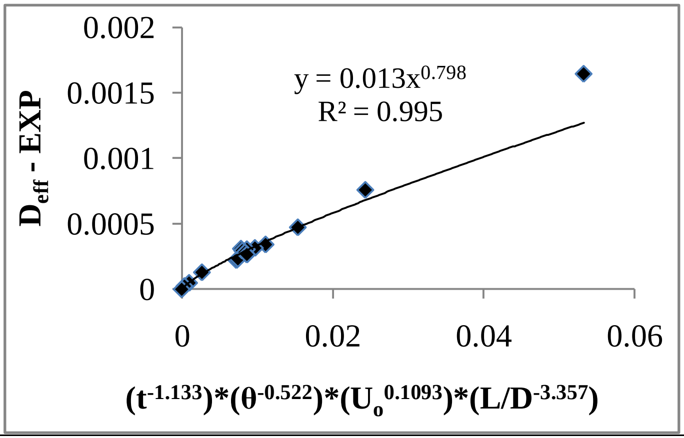


Fig -13: Correlation plot for the mushroom

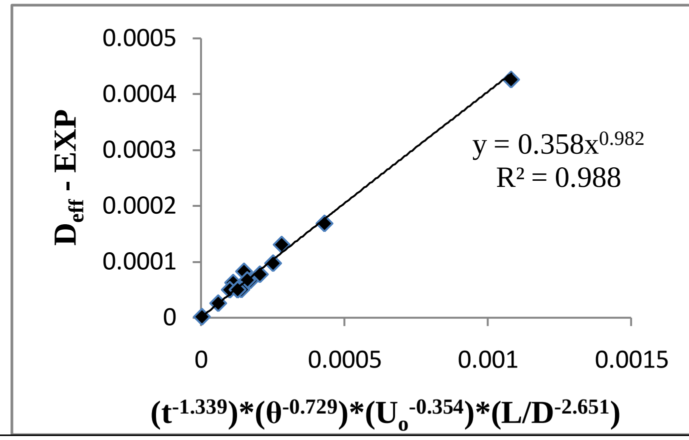


Fig -14: Correlation plot for the vegetables

Fig. - 13 & 14: The correlation plots for diffusivity of the samples against the system parameters

4.5 ANN Analysis for Diffusivity

The outputs of the ANN-learning for diffusivity calculations were evaluated. The developed correlations for diffusivity are as follows.

For Mushrooms:

$$D_{eff} = 0.07 \times \left[(t)^{1.33} (\theta)^{0.72} (U_o)^{0.32} \left(\frac{L}{D} \right)^{2.65} \right]^{0.85} \tag{14}$$

For Vegetables:

$$D_{eff} = 0.28 \times \left[(t)^{1.15} (\theta)^{0.08} (U_o)^{0.36} \left(\frac{L}{D} \right)^{1.75} \right]^{0.98} \tag{15}$$

The effective moisture diffusivity of the mushroom and different vegetables were also calculated using Artificial Neural Network. The calculated values thus obtained were compared against the experimentally observed values and root mean square (RMS) error was calculated. The plots of RMS error against the number of cycles or epoches for both, the mushroom and vegetables are shown in Fig. - 15 and 16 respectively.

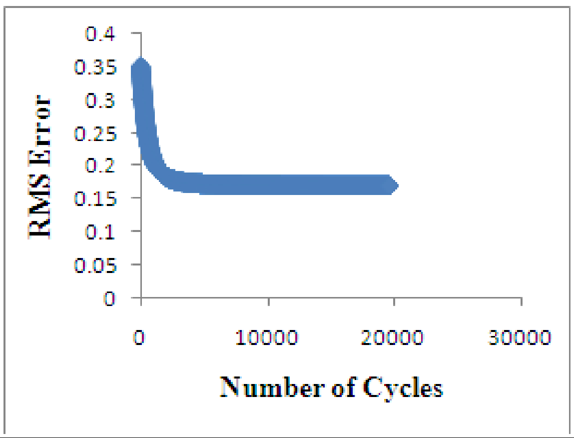


Fig -15: The RMS Error plot for mushroom

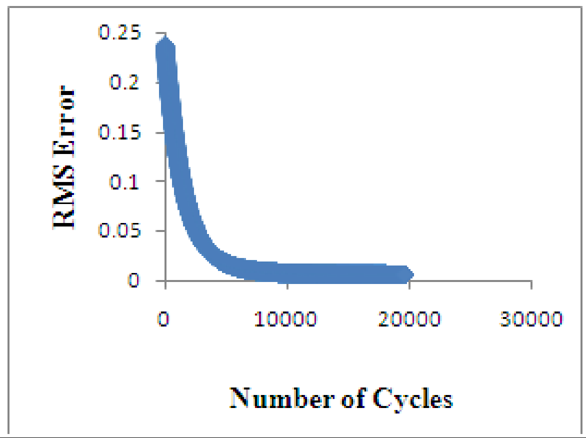


Fig -16: The RMS Error plot for vegetables

Fig.- 15 & 16: The plots of RMS error obtained from ANN-learning against the number of epoches for both the mushroom and vegetables

It is observed that the RMS error for vegetables is almost negligible for the vegetables in comparison with the Mushrooms. RMS error for Mushrooms started from 0.35 at 0 numbers of epoches and decreased to 0.17 at 100 numbers of epoches which remained constant over 20000 numbers of epoches. RMS error for vegetables started from o.25 at 0 number epoches to 0.001 at number of epoches which remained constant over 20000 numbers of epoches.

4.6 Drying Kinetics

The drying curves were obtained for different samples which show that drying mainly occurs in the falling period. Sample plots for each sample are shown in Fig- 17. The effective moisture diffusivity were also calculated using eq^n-6 for different samples. The activation energy was also calculated for different samples using eq^n-7 and slopes of D_{eff} vs. 1/T.

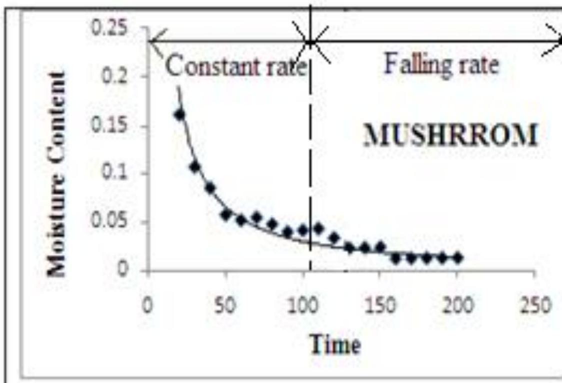


Fig. - 17(A): Time vs Moisture Content

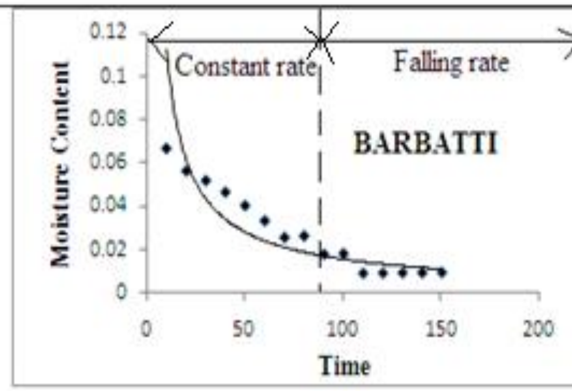


Fig. - 17(B): Time vs Moisture Content

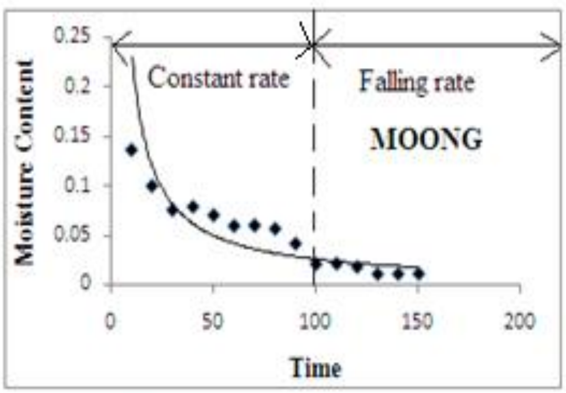


Fig. - 17(C): Time vs Moisture Content

CHAPTER V

Discussions

Attempts have been made to study the drying characteristics of different grains and vegetables through a fluidized bed drier in the present study. Correlations have been developed for the drying characteristics in terms of the moisture content of the grains and diffusivity of the vegetables by relating the experimentally observed values of the moisture content and diffusivity of the sample against the different system parameters. The calculated values of the moisture content and diffusivity of different grains, mushrooms and vegetables have been compared with the experimentally observed values.

The drying characteristics (i.e. for moisture content and diffusivity) of the samples have been calculated by using both Dimensional and Artificial Neural Network analysis and listed in Table - 3 and Table - 4. The comparison of calculated values of moisture content of grains and vegetables has been done in Table - 3(A) and Table - 3(B) respectively. Similarly the diffusivity values calculated by Dimensional and ANN have been compared with the experimental values in Tables - 4(A) and 4(B) for mushrooms and vegetables respectively.

The drying curves for different samples are shown in Fig. - 17 it is observed that the drying process of vegetables Fig. - 17 (A) & (B) mostly occurs in the falling rate period and moisture transfer during drying is controlled by internal diffusion. Fick's second law of diffusion is applicable for the drying process during the falling rate period. It is also observed that the drying process of moong occur in the falling period Fig. - 17 (C).

Thus the effective moisture diffusivity, D_{eff} was calculated using the slopes for drying curves and Eq^n.- (6). The calculated values of effective moisture diffusivity for different samples are listed in Table -5. The time of drying is observed to affect the effective moisture diffusivity of mushroom and other vegetables. It is observed that the moisture diffusivity decreases with the increase in drying time.

Activation energies for different samples are calculated using the Arrhenius expression i.e. Eq. -(7) and listed in Table - 6. It is observed that at different drying temperatures, during the initial stage of drying, vegetables have registered the highest activation energy. It is also observed that the activation energy increases with increase in time for Mushroom, Tundli and Potato whereas as observed the activation energy for grain (green gram or moong) decreases with increase in time. In case of Moong, activation energy is found to be maximum indicating that moisture removal from hard material is not so easy. It is also clear from Table - 6 that vegetables require minimum activation energy to detach and move the water during the drying process.

The calculated values of moisture content and effective moisture diffusivity of grains/mushrooms and other vegetables have been compared with each other and with their experimental values. The standard deviations and mean deviations of these measurements are listed in Table - 7. These deviations indicate that the developed correlations can be used over a wide range of parameters. The very low value of standard and mean deviation for ANN approach indicates very good validation of the Dimensional Analysis approach. The outputs of the ANN-models (a, b, c, d, $K^{'}$, n) for both the moisture content and diffusivity of different grains and vegetables have been compared with the outputs obtained through the Dimensional Analysis as shown in Table - 8. The mass transfer coefficients for different samples subjected to fluidized bed drying have also been calculated and plotted against the temperature to get the mass transfer kinetic equations of different grains and vegetables which are listed in Table - 9. Weights obtained from ANN-learning of different samples have been listed in Annexure - 1.

Table - 3(A): Observed data and comparison of calculated values of moisture content of grains different methods against the experimental values of moisture content

Sl No.	t/t_{max}	θ/θ_{max}	U_o/U_{oma}	ρ_s/ρ_f	M_C-EXP	D.A.	ANN	D.A.	ANN
						M_C-CAL	M_C-CAL	%D	%Dev.
1	0.2	1	1	1152.765	0.503	0.516	0.675	-	8.77
2	0.4	1	1	1152.765	0.308	0.257	0.342	16.5	6.57
3	0.6	1	1	1152.765	0.197	0.171	0.230	13.1	4.28
4	0.8	1	1	1152.765	0.141	0.128	0.174	9.33	6.96
5	1	1	1	1152.765	0.102	0.102	0.139	0.02	-1.81
6	1	0.6	1	1152.765	0.336	0.348	0.406	-	8.16
7	1	0.8	1	1152.765	0.151	0.177	0.226	-	3.41
8	1	1	1	1152.765	0.102	0.102	0.139	0.02	-1.81
9	1	1	0.2	1152.765	0.177	0.193	0.236	-	3.68
10	1	1	0.5	1152.765	0.133	0.140	0.180	-	18.93
11	1	1	0.7	1152.765	0.095	0.116	0.155	-	-10.72
12	1	1	1	1152.765	0.102	0.102	0.139	0.02	-1.81
13	1	1	1	1030.928	0.141	0.124	0.167	12.0	25.35
14	1	1	1	1138.707	0.091	0.104	0.142	-	-14.27
15	1	1	1	1152.765	0.102	0.102	0.139	0.02	-1.81
16	1	1	1	1271.79	0.099	0.087	0.119	12.1	-5.08

Table - 3(B): Observed data and comparison of calculated values of moisture content of vegetables by different methods against the experimental values of moisture content

Sl No.	t/t_{max}	θ/θ_{max}	U_o/U_{omax}	L/D	M_C-EXP	D.A.	ANN	D.A.	ANN
						M_C-CAL	M_C-CAL	%Dev	%Dev.
1	0.2	1	1	1.2	128.42	124.394	104.380	3.13	18.71
2	0.4	1	1	1.2	123.42	117.847	106.061	4.51	14.06
3	0.6	1	1	1.2	119.42	114.178	107.056	4.38	10.35
4	0.8	1	1	1.2	116.42	111.644	107.768	4.10	7.43
5	1	1	1	1.2	114.42	109.717	108.324	4.10	5.32
6	1	0.5714	1	1.2	132.22	125.852	95.220	4.81	27.98
7	1	0.7143	1	1.2	114.42	119.152	100.243	-4.13	12.38
8	1	0.8571	1	1.2	130.60	113.943	104.544	12.75	19.95
9	1	1	0.2	1.2	109.60	127.677	79.289	-16.49	27.65
10	1	1	0.5	1.2	131.92	118.186	92.952	10.41	29.53
11	1	1	0.7	1.2	119.10	113.181	101.610	4.96	14.68
12	1	1	1	1.2	98.80	109.717	108.324	-11.05	-9.63
13	1	1	1	1.2	114.42	109.717	108.324	4.10	5.32
14	1	1	1	0.8	119.48	127.245	101.317	-6.49	15.20
15	1	1	1	1.2	114.42	109.717	108.324	4.10	5.32
16	1	1	1	1.6	74.60	95.130	115.525	-27.52	-14.86
17	1	1	1	5.2	55.27	53.023	150.386	4.06	-17.09

Table - 4(A): Observed data and comparison of calculated values of Diffusivity of Mushroom by different methods against the experimental values of Diffusivity

Sl No.	t/t_{max}	θ/θ_{max}	U_o/U_{omax}	L/D	D_{eff} -EXP	D.A.	ANN	D.A.	ANN
						D_{eff} -CAL	D_{eff} -CAL	%Dev.	%Dev.
1	10	50	3.8	0.6	0.001	0.001	0. 9 E-04	19.14	4.95
2	20	50	3.8	0.6	0.7 E-04	0. 6 E-04	0. 5 E-04	8.26	29.31
3	30	50	3.8	0.6	0.4 E-04	0. 4 E-04	0.3 E-04	-0.72	19.92
4	40	50	3.8	0.6	0.3 E-04	0. 3 E-04	0.3 E-04	-6.38	13.52
5	50	50	3.8	0.6	0.2 E-04	0. 2 E-04	0.2 E-04	-11.04	8.16
6	50	40	3.8	0.6	0.3 E-04	0. 3 E-04	0.3 E-04	-3.11	10.41
7	50	50	3.8	0.6	0.3 E-04	0. 2 E-04	0.2 E-04	3.31	20.03
8	50	60	3.8	0.6	0.3 E-04	0. 2 E-04	0.2 E-04	11.82	29.95
9	50	70	3.8	0.6	0.2 E-04	0. 2 E-04	0.2 E-04	-14.87	11.80
10	50	50	0.97	0.6	0.2 E-04	0.2 E-04	0.1 E-04	-12.38	21.48
11	50	50	1.95	0.6	0.2 E-04	0.2 E-04	0.2 E-04	5.67	28.17
12	50	50	2.87	0.6	0.2 E-04	0.2 E-04	0.2 E-04	-1.94	18.55
13	50	50	3.8	0.6	0.2 E-04	0.2 E-04	0.2 E-04	-11.04	8.16
14	50	50	3.8	0.6	0.2 E-04	0.3 E-04	0.2 E-04	-11.03	8.16
15	50	50	3.8	0.8	0.1 E-04	0.1 E-04	0.1 E-04	13.38	16.02
16	50	50	3.8	1.2	4.97E-04	4.94E-05	0.5 E-04	0.70	-10.32
17	50	50	3.8	1.6	2.54E-04	2.23E-05	0.3 E-04	12.20	-11.21
18	50	50	3.8	5.2	1.12E-04	8.54E-07	0.1 E-04	23.59	-6.65

Table - 4(B): Observed data and comparison of calculated values of Diffusivity of vegetables by different methods against the experimental values of Diffusivity

Sl No.	t/t_{max}	θ/θ_{max}	U_o/U_{omax}	L/D	D_{eff} -EXP	D.A.	ANN	D.A.	ANN
						D_{eff} -CAL	D_{eff} -CAL	%Dev.	%Dev.
1	10	50	3.8	1.2	0. 4 E-04	0.001	0.3 E-04	-2.75	25.53
2	20	50	3.8	1.2	0. 1 E-04	0.6 E-04	0.1 E-04	-5.19	14.03
3	30	50	3.8	1.2	9.7E-05	0.4 E-04	9.14E-05	-7.47	5.77
4	40	50	3.8	1.2	6.61E-05	0.3 E-04	6.59E-05	-8.33	0.16
5	50	50	3.8	1.2	4.97E-05	0.2 E-04	5.12E-05	-7.55	-3.02
6	50	40	3.8	1.2	8.24E-05	0. 3 E-04	6.21E-05	23.94	24.50
7	50	50	3.8	1.2	4.97E-05	0. 2 E-04	5.12E-05	-7.55	-3.02
8	50	60	3.8	1.2	6.22E-05	0. 2 E-04	4.37E-05	24.40	29.66
9	50	70	3.8	1.2	4.95E-05	0. 2 E-04	3.82E-05	14.73	22.59
10	50	50	0.97	1.2	7.72E-05	0. 2 E-04	8.35E-05	-10.67	-8.31
11	50	50	1.95	1.2	6.69E-05	0. 2 E-04	6.51E-05	-0.61	2.60
12	50	50	2.87	1.2	4.99E-05	0. 2 E-04	5.66E-05	-17.96	-13.49
13	50	50	3.8	1.2	4.97E-05	0. 2 E-04	5.12E-05	-7.55	-3.02
14	50	50	3.8	0.8	0.0001	0. 2 E-04	8.57E-05	10.69	34.20
15	50	50	3.8	1.2	4.97E-05	0. 1 E-04	5.12E-05	-7.55	-3.02
16	50	50	3.8	1.6	2.54E-05	4.94E-05	3.12E-05	0.29	-22.97
17	50	50	3.8	5.2	1.12E-06	2.23E-05	4.09E-06	-5.38	-26.07

Table - 5: Effective Diffusivity of Moisture for Samples

TIME	SAMPLES					
	Mushroom	**Potato**	**Tundli**	**Barbatti**	**Radish**	**Ladys finger**
	Effective Diffusivity					
10	0.0016	7.801E-06	4.330E-05	2.809E-05	0.001	0.5 E-04
20	0.0007	2.404E-06	1.710E-05	9.393E-06	0.4 E-04	0. 1 E-04
30	0.0004	9.156E-07	9.860E-06	4.386E-06	0.2 E-04	9.008E-05
40	0.0003	4.261E-07	6.718E-06	2.232E-06	0.1 E-04	4.799E-05
50	0.0002	2.324E-07	5.056E-06	1.118E-06	0.1 E-04	2.537E-05

Table - 6: Activation energy values for different samples at different times

		Activation Energy (Ea)			
SL NO.	**TIME, min**	**MOONG**	**MUSHROOM**	**TUNDLI**	**POTATO**
1	10	207358.642	5162.348	26372.959	4448.981
2	20	206543.840	6210.782	26589.131	9802.559
3	30	202403.319	7292.472	27686.619	12953.679
4	40	187362.750	8261.088	29440.936	17559.801
5	50	161945.935	9037.644	30920.881	27936.048

Table - 7: Comparisons of deviations of calculated values of drying characteristics from experimentally observed values for different Samples

		D.A.		ANN	
Sl No.	SAMPLES	Std. Dev.	Mean Dev.	Std. Dev.	Mean Dev.
1	M_C for Grains	11.313	-0. 602	0.143	0.226
2	M_C for Vegetables	10.195	-0.012	14.065	105.861
3	D_{eff}. of Mushroom	11.532	1.421	0.2 E-04	0.3 E-04
4	D_{eff}. of Vegetables	12.097	-0.855	0.6 E-04	0.7 E-04

Table - 8: The outputs obtained through Dimensional Analysis and ANN-analysis for different samples

Sl No.	Out Puts	Moisture Content for grains		Moisture Content for vegetables		Diffusivity of mushroom		Diffusivity of vegetables	
		D.A.	ANN	D.A.	ANN	D.A.	ANN	D.A.	ANN
1	a	-0.98	0. 93	-0.07	0.45	-1.13	1.33	-1.33	1.15
2	b	-2.94	1.14	-0.22	0.44	-0.52	0.72	-0.72	0.08
3	c	-0.45	1.03	-0.15	0.44	0.11	0.32	-0.35	0.36
4	d	-1.65	1.03	-0.44	0.43	-3.35	2.65	-2.65	1.75
5	K'	1517	1219	120.63	103.99	0.01	0.07	0.35	0.28
6	n	1.02	1.05	1.11	0.51	0.79	0.85	0.98	0.98

Table - 9: The developed transfer coefficient equations for different samples

Sl No.	Grains	Kinetic Equation	Vegetables	Kinetic Equation
1	Wheat	$F= 0.0034\ e^{107.74/\theta}$	Mushroom	$F= 0.0341\ e^{862.79/\theta}$
2	Mustard	$F= 0.0023\ e^{107.75/\theta}$	Tundli	$F= 0.0004\ e^{1093.4/\theta}$
3	Rice	$F= 0.0014\ e^{107.86/\theta}$	Potato	$F= 6E\text{-}07\ e^{2435.4/\theta}$
4	Moong	$F= 0.0012\ e^{108.24/\theta}$		

CHAPTER VI

Conclusion

Fluidized bed dryer are mostly used in food and pharmaceutical industries. For pharmaceutical purpose, minimum moisture content can be removed through fluidized bed dryer by maintaining the optimum parametric conditions. In present studies the drying performances of fluidized bed dryer were observed experimentally by varying four different system parameters viz. temperatures, times of drying, velocity of air and density of material.

The drying performance of fluidized bed dries has been studied by analyzing moisture content and diffusivity of the sample during drying operation. Attempts were also made to develop correlations for these drying performances of the fluidized bed dryer on the basis of Dimensional Analysis which further has been validated by Artificial Neural Network approach. The drying performances eventually affect the drying efficiency of the dryer. As the standard deviations and mean deviations obtained on comparison with the experimental values are very low indicating the validity of the correlation to be very good. Therefore the developed correlations can be used over a wide range of parameters. Heat transfer, mass transfer along with their kinetics were also analysed during drying of different samples in the present study.

The drying characteristics of different samples such as grains, mushrooms and vegetables were studied through the moisture content and diffusivity of the samples. The effect of different system parameters on the drying characteristics were studied by developing correlations on the basis of dimensional analysis. Knowledge of such effects gives the base of the design by which the efficiency of the fluidized bed dryer can be improved or the process can be effectively optimized. Kinetics of drying for grains and vegetables were also observed through the measurement of activation energy and mass transfer coefficients. Knowledge of activation energy will be a great help for optimization of the drying operation thereby minimizing the wastage of energy during drying of any sample.

Mainly the temperature parameter was found to control the drying rate and thus the drying times. As the drying time is a function of the moisture content of sample, increase in drying air temperature decreases the drying time. The drying process was observed to occur in both falling rate and constant rate periods.

The coefficients of the developed models and the apparent diffusion coefficients are the most important parameters for the transferring of moisture. These were also found to be dependent on the temperature and velocity of the drying air. The effect of temperature on the diffusivity was expressed by the Arrhenius equation where the logarithm of the diffusivity exhibited a lineal behavior against the reciprocal of the absolute temperature.

The very good agreement between ANN-model and experimental data proved that the neural network learned training is proper and it well the behavior of the different parameters. Based on the error analysis results, it is also found out that the neural network with the selected neurons and the transfer function with back propagation algorithm are the most appropriate ANN configuration for drying time prediction purposes. The selected ANN model successfully learned the relationship between the input parameters and output parameters. Therefore, the suggested neural network can easily be used to normalize the experimental data of the drying process investigated for different conditions.

Finally it can also be suggested that the developed correlation can be suitably used for the industrial drying purpose with a suitable scale-up factor. Otherwise the developed correlation can be considered as the base design for a industrial fluidized bed dryer (large scale) with an optimum drying process.

Future Work

- CFD analysis can be done to understand the drying mechanism.
- Further drying experiments can be carried out with different pharmaceuticals, thus the observed data can be verified with the developed correlations.

NOMENCLATURES:

a, b, c, d:		Exponent of individual parameter
D_{eff}	:	Effective diffusivity, $m^2\ s^{-1}$
Ea	:	Activation energy, $kJ\ mol^{-1}$
F	:	Mass transfer coefficient, $mole/m^2.K$
K	:	Drying rate
K'	:	Overall co-efficient
L	:	Length of the sample, cm
M_c	:	Moisture content, kg
M	:	Moisture at given time, kg/kg d.b.
M_o	:	Initial moisture, kg/kg d.b.
M_e	:	Equilibrium moisture content, kg/kg d.b.
M_R	:	Moisture ratio
n	:	Overall exponent
r	:	Slab thickness, centimeters
R	:	Universal gas constant, $mol^{-1}K^{-1}$
t	:	Drying time, minute
T	:	Absolute temperature, ^oK
U_o	:	Velocity of the fluidizing medium, m/s
W_b	:	Weight of materials before drying, kg
W_d	:	Weight of materials after drying, kg
W_i	:	Initial Weight, kg
W_f	:	Final Weight, kg

Greek letters

ρ	:	Density, kg/m^3
θ	:	Temperature , ^0C
η	:	Drying efficiency

Subscript

s	:	For solid
f	:	For fluid
max	:	For maximum

Abbreviations

ANN	:	Artificial Neural Network
D-cal	:	Calculative values of diffusivity
D-Exp	:	Experimental values of diffusivity
RMS	:	Root Mean Square
Std	:	Standard Deviation

REFERENCES:

1. Kazarian, E.A. Hall CW "Thermal properties of Grain." 'Trans of the ASAE' 8: 33-37, (1965).
2. Hii, C.L., C.L. Lawb, M. Clokea and S. Suzannahb "Thin layer drying kinetics of cocoa and dried product quality.", 'Biosystems Engineering' 102, 153-161, (2008).
3. Ibrahim, M.K. Sopian and W.R.W. Daud "Study of the Drying Kinetics of Lemon Grass." 'American Journal of Applied Sciences' 6 (6): 1070-1075, (2009).
4. Arumuganathan1, T., M.R. Manikantan, R.D. Rai1, S. Anandakumar and V. Khare "Mathematical modeling of drying kinetics of milky mushroom in a fluidized bed dryer." 'International Agrophysics'; 23, 1-7, (2009).
5. Amiri Chayjan, R., J. A. Parian and M. E. Ashari "Modeling of moisture diffusivity, activation energy and specific energy consumption of high moisture corn in a fixed and fluidized bed convective dryer" Spanish Journal of Agricultural Research, 9(1), 28-40 (2011).
6. Kossovich, P.S. and A.F. Lebedev 'Journal of Engineering Physics and Thermodynamics'; volume 13 November, (1967).
7. Fulford, G.D. "A survey of Soviet Research on the drying of solids." 'Canadian Journal of Chemical Engineering'; 47, 378 – 391, (1969).

8. Ginzburg, A.S. “Grain drying and grain dryers.” ‘Publication of Technical Economic Literature on flour milling and cereals’; Moscow, (1958).
9. Hallstron, A. and R.W. Stedt “Drying of Porous granular materials.” ‘Journal of Chemical Engineering Science’; Vol.38 (9), 1507 – 1516, (1983).
10. Tulasidas, T.N., T. Kudra, G.S.V Raghavan, and A.S. Mujundhar “Effect of bed height on simultaneous heat and mass transfer in spouted bed dryer.” ‘International Com. Heat and mass transfer Journal’; Vol.20 (1), 79 -88, (1993).
11. Bilgin, K., E.P. Ralph and T. cakaloz. “Generalized drying curves for porous solids.” ‘The Canadian Journal of Chemical Engineering’; Vol.53, 53 – 59, (1975).
12. Anantharaman, N. and S. Sundharam “Comparative study of drying of raagi in fluidized and infarared bed dryer.” ‘51st annual session of Indian institute of chemical engineers’; Chemcon – 98, Ts – 1218, Page. 193, (1998).
13. Simmonds, W.H.C, G.T. Ward and E. McEwen “The drying of wheat grain, Part 1: The mechanisms of drying.” ‘Trans Institute Chemical Engineering’; 32:265-78, (1953).
14. Chandran, A.N., S.S. Rao and Y.B.G. Varma “Fluidized bed drying of solids.” ‘AIChE Journal’; 36(1):29–38, (1990).
15. Abid, M., R. Gibert and C. Laguerie “An experimental and theoretical analysis of the mechanisms of heat and mass transfer during the drying of corn grains in a fluidized bed.” ‘International Chemical Engineering’; 30(4):632–42, (1990).
16. Thomas, P.P. and Y.B.G. Varma “Fluidized bed drying of granular food materials.” ‘Powder Technology’; 69:213–22, (1992).
17. Watano, S., N. Yeh and K. Miyanami “Drying of granules in agitation fluidized bed.” ‘Journal of chemical Engineering Japan’; 31(6):908–13, (1998).

18. Gaston, A.L., R.M. Abalone and S.A. Giner "Wheat drying kinetics, Diffusivities for sphere and ellipsoid by finite elements." 'Journal of Food Engineering'; vol 52, no-4, 313-322, (2002).

19. Chalida, N., and D. Sakamon "Drying kinetics and quality of coconut dried in a fluidized bed dryer." 'Journal of Food Engineering'; 66, 267–271, (2005).

20. Krokida, M.K., E. Foundoukidis and Z. Maroulis "Drying constant: literature data compilation for foodstuffs." 'Journal of Food Engineering'; 61, 321–330, (2004).

21. Simpson, W.T. "Effect of air velocity on drying rate of single eastern white pine boards." Res. Note FPL–RN–266. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.5 p., (1997).

22. Ndukwu, M.C. "Effect of Drying Temperature and Drying Air Velocity on the Drying Rate and Drying Constant of Cocoa Bean." 'Agricultural Engineering International, the CIGRE journal' Manuscript 1091. Vol. XI., April, (2009).

23. Amin, T.G., and K.A. Rafiee "Study on Effective moisture diffusivity, activation energy and mathematical modeling of thin layer drying kinetics of bell pepper." AJCS 5(2):128-131 ISSN: 1835-2707, (2011).

24. Srinivasakannan, C. and N. Balasubramanian "An Analysis on Modeling of Fluidized Bed Drying of Granular Material." 'Advanced Powder Technology'; 19, 73–82, (2008).

25. Walde, S.G., V. Velu, T. Jyothirmayi, and R.G. Math "Effects of pretreatments and drying methods on dehydration of mushroom." 'Journal of Food Engineering'; 74, 108–115, (2006).

26. Chandrasekar, S. "Modeling Drying Kinetics of Mustard in Fluidized Bed." 'International Journal of Food Engineering'; Volume 4, Issue 3, Article 6, (2008).

27. Mirzaee1, E., S. Rafiee1, A. Keyhanil, and Z. Emam-Djomeh “Determining of moisture diffusivity and activation energy in drying of apricots.” ‘Research Agriculture Engineering’; *55*, (3): 114 – 120, (2009).

28. Nwabanne, J.T. “Drying characteristics and engineering properties of fermented ground cassava.” ‘African Journal of Biotechnology’; Vol. 8 (5), pp. 873-876, ISSN 1684–5315 (C) Academic Journals, 6 March, (2009).

29. Meisami-asl, E., S. Rafiee, A. Keyhani and A. Tabatabaeefar “Determination of suitable thin layer drying curve model for apple slices.” ‘Journal of (variety-Golab), Plant Omics’; 3(3):103-108, (2010).

30. Hatamipour, M.S. and D. Mowla “Correlations for shrinkage, density and diffusivity for drying of maize and green peas in a fluidized bed with energy carrier.” ‘Journal of Food Engineering’; 59, 221–227, (2003).

31. Supawan, T., S. Prachayawarakorn and S. Soponronnarit “Drying Strategies based on Diffusion model and Energy Analysis for Fluidized-Bed Drying of Paddy.” ‘Department of Chemical Engineering, Faculty of Engineering, Prince of Songkla University Hatyai, Songkhla, Thailand 90112.’ (2004).

32. Ademiluyi, T., E.O. Oboho and O. Michael “Investigation into the Thin Layer Drying Models of Nigerian Popcorn Varieties.” ‘Leonardo Electronic Journal of Practices and Technologies’; ISSN 1583-1078 p. 47-62, (2008).

33. Hassini, L., S. Azzouz, R. Peczalski, and A. Belghith “Estimation of potato moisture diffusivity from convective drying kinetics with correction for shrinkage.” ‘Journal of Food Engineering’; 79, 47–56, (2007).

34. Mustafa, I., K. Sopian and W.R.W. Daud "Study of the Drying Kinetics of Lemon Grass." 'American Journal of Applied Sciences'; 6 (6): 1070-1075, (2009).

35. Zbey, M. O., and M.S. Soylemez "Effect of swirling flow on fluidized bed drying of wheat grains." 'Energy Conversion and Management'; 46, 1495–1512, (2005).

36. Satish, S., and Y.P. Setty "Modeling of a continuous fluidized bed dryer using artificial neural networks." 'International Communications in Heat and Mass Transfer'; 32, 539–547, (2005).

37. Nazghelichi, T., H.K. Mohammad and A. Mortaza "Prediction of carrot cubes drying kinetics during fluidized bed drying by artificial neural network." 'Journal Food Science Technology'; DOI 10.1007/s13197-010-0166-2, (2010).

38. Amiri, C.R., G.A. Montazer, T.T. Hashjin, M.H. Khoshtaghaza and G. Barat "Prediction of Pistachio Thermal Conductivity Using Artificial Neural Network Approach." 'International journal of agriculture and biology'; 1560–8530/09–6–816–820, (2007).

39. Tiwari, A., and J.P. Pandey "Modeling of High Velocity Hot Air-Recirculatory Tray Drying of Sweet Pepper using Artificial Neural Network (ANN) and Response Surface Methodology (RSM)." 'Assam University Journal of Science and Technology: Physical Sciences and Technology'; Vol. 4 Number II 29-39, (2009).

40. Shivmurti, S. and B.K. Kumbhar "Drying kinetics and ANN modeling of paneer at low pressure superheated steam." 'Journal Food Science Technology'; DOI 10.1007/s13197-010-0167-1, (2010).

41. Marius, S.S., D. Rodica, P. Camelia and P. Stelian "ANN modeling and simulation of gas drying by adsorption on composite materials." ISBN: 978-0-9553018-8-9 / ISBN: 978-0-9553018-9-6 (CD), (2008).

42. Koni, M., U. Yuzgec, H. Dinc-er and H. Kapucu “Adaptive modeling of the drying of baker’s yeast in a batch fluidized bed” Control Engineering Practice; 17 ,503–517, (2009).

43. Menlik, T., V. Kirmaci and Hüseyin USTA “Modeling of freeze drying behaviors of strawberries by using Artificial neural network.” Isı Bilimi ve Tekniği Dergisi, 29, 2, 11-21, ‘Journal of Thermal Science and Technology’; ©2009 TIBTD Printed in Turkey ISSN 1300-3615, (2009).

44. Zhang, Q. and S.K. Yang “Modeling and Parameter Optimization of Rough Rice Drying using Artificial Neural Networks.” 0-7803-7278-6/02/$10.00 ©2002 IEEE, (2002).

45. Khoshhal, A., A.D. Asghar, E. Ahmad, and Z. Sina “Artificial neural network modeling of apple drying process” ‘Journal of food process engineering’; volume 33, issue supplement s1, pages 298–313, (2010).

ANNEXURE - 1

Weights of ANN Learning

Table - 1

For moisture content of grains:

Weight of training dataset - 1

25000 - CYCLES

input to hidden layer weights

w1[0][1] = 1.164237 w1[0][2] = 1.311587 w1[1][1] = -0.061339 w1[1][2] = 0.061748

w1[2][1] = 0.017071 w1[2][2] = -0.003300 w1[3][1] = -0.029836 w1[3][2] = 0.079192

w1[4][1] = 0.064568 w1[4][2] = 0.049321 w1[5][1] = 0.000000 w1[5][2] = 0.00000

hidden layer to o/p layer weights

w2[0][0] = -2.004973 w2[0][1] = -1.899719 w2[0][2] = -1.899152 w2[0][3] = -1.945219

w2[0][4] = -0.320941 w2[0][5] = -2.015513 w2[1][0] = -1.200505 w2[1][1] = -1.156764

w2[1][2] = -1.181803 w2[1][3] = -1.182261 w2[1][4] = -0.051269 w2[1][5] = -1.117270

w2[2][0] = -1.247911 w2[2][1] = -1.283708 w2[2][2] = -1.266858 w2[2][3] = -1.194886

w2[2][4] = -0.150672 w2[2][5] = -1.148192

Table - 2

For moisture content of vegetables:

Weight of training dataset - 2

20000 - CYCLES

input to hidden layer weights

w1[0][1] = 0.795117 w1[0][2] = 0.916524 w1[1][1] = 0.676824 w1[1][2] = 0.801690 w1[2][1] = 0.022667 w1[2][2] = 0.001685 w1[3][1] = -0.025124 w1[3][2] = 0.083367w1[4][1] = 0.069878 w1[4][2] = 0.055329 w1[5][1] = 0.000000 w1[5][2] = 0.000000

hidden layer to o/p layer weights

w2[0][0] = -1.666777 w2[0][1] = -1.613919 w2[0][2] = -1.612782 w2[0][3] = -1.670750 w2[0][4] = 0.403675 w2[0][5] = -1.685609 w2[1][0] = -1.031415 w2[1][1] = -1.024588 w2[1][2] = -1.048517 w2[1][3] = -1.062183 w2[1][4] = 0.350977 w2[1][5] = -0.952796 w2[2][0] = -1.113013 w2[2][1] = -1.187858 w2[2][2] = -1.165938 w2[2][3] = -1.109729 w2[2][4] = 0.288314 w2[2][5] = -1.009341

Table - 3

For diffusivity of mushroom:

Weight of training dataset - 3

20000 - CYCLES

input to hidden layer weights

w1[0][1] = 350.567505 w1[0][2] = 200.497620 w1[1][1] = -0.048575 w1[1][2] = 0.068990 w1[2][1] = 39.730114 w1[2][2] = 22.686586 w1[3][1] = 226.705704 w1[3][2] = 129.695084 w1[4][1] = 17.358318 w1[4][2] = 9.933708 w1[5][1] = 0.000000 w1[5][2] = 0.000000

hidden layer to o/p layer weights

w2[0][0] = -4.357804 w2[0][1] = -6.895851 w2[0][2] = -2.932073 w2[0][3]=-7.791589 w2[0][4] = 121902480.000000 w2[0][5] = -0.591789 w2[1][0] = -4.374531 w2[1][1] = -6.995813 w2[1][2] = -3.041407 w2[1][3] = -7.862414 w2[1][4] = 121902480.00000 w2[1][5] = -0.506408 w2[2][0] = -4.368929 w2[2][1] = -7.068745 w2[2][2] = -3.068040 w2[2][3] = -7.819252 w2[2][4] = 121902480.000000 w2[2][5] = -0.478302

Table - 4

For diffusivity of vegetables:

Weight of training dataset - 4

20000 – CYCLES

input to hidden layer weights

w1[0][1] = 2.019238 w1[0][2] = 2.074821 w1[1][1] = -0.061339 w1[1][2] = 0.061748

w1[2][1] = 1.228194 w1[2][2] = 1.175717 w1[3][1] = 1.424996 w1[3][2] = 1.495038

w1[4][1] = 0.163846 w1[4][2] = 0.146140 w1[5][1] = 0.000000 w1[5][2] = 0.000000

hidden layer to o/p layer weights

w2[0][0] = -4.203183 w2[0][1] = -2.806844 w2[0][2] = -2.006096 w2[0][3] = -6.592771

w2[0][4] = -1.314862 w2[0][5] = -0.755826 w2[1][0] = -3.338596 w2[1][1] = -2.231783

w2[1][2] = -1.566668 w2[1][3] = -5.466899 w2[1][4] = -0.752985 w2[1][5] = -0.413776

w2[2][0] = -3.432730 w2[2][1] = -2.387677 w2[2][2] = -1.659867 w2[2][3] = -5.578706

w2[2][4] = -0.894421 w2[2][5] = -0.418615